TWO-KEY CONCURRENT RESPONDING: CHOICE AND DELAYS OF REINFORCEMENT AT CONSTANT RELATIVE IMMEDIACY OF REINFORCEMENT

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TWO-KEY CONCURRENT RESPONDING: CHOICE AND DELAYS OF REINFORCEMENT AT CONSTANT RELATIVE IMMEDIACY OF REINFORCEMENT

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LIST OF SYMBOLS

Several of the following symbols have two meanings. In each case the text will indicate the appropriate meaning.

Symbol	
d	delay of reinforcement
e	experimental key
l	left key or long-delay key
n	number of reinforcers per entry into terminal link
r	right key
s	standard key or short-delay key
t	time or initial link duration
A	magnitude of reinforcement
CO	number of changeovers
E	ratio of obtained to scheduled entries into a terminal link
I	immediacy of reinforcement (1/d)
LR	local response rate
P	number of responses
R	number of reinforcements or reinforcement rate
RD	duration of reinforcement sequence
RT	time spent on a key including reinforcements and changeovers
SD	session duration
T	time allocation or expected time to reinforcement
V	value of a reinforcer
X	unknown parameter of reinforcer

SUMMARY

Several previous studies concluded that if reinforcements are delayed under two-key concurrent variable-interval schedules of reinforcement, then the relative frequency of responding on the key associated with the shorter delay matched the relative immediacy of reinforcement, immediacy of reinforcement being the reciprocal of the delay of reinforcement.

Other studies have found that the relative reciprocal function also applied to choice between two interresponse times. The relative frequency of the shorter interresponse time matched the relative reciprocal of that interresponse time. It was subsequently demonstrated that two variables affected this relative reciprocal relation: the absolute durations of the interresponse times and the overall rate of reinforcement.

The present experiment was designed to determine the effects of the absolute durations of delays on choice under two-key concurrent variable interval schedules of reinforcement. The relative immediacy of reinforcement was held constant at 0.80 (i.e., the duration of one delay was four times the duration of the other) and the durations of the delays were varied. The subjects were four pigeons. At the shorter absolute delays, there was a preference for the shorter delay,

but the degree of preference was less than 0.80 (which is required by the matching relation). At the mid-range durations of delays, the preference for the shorter delay attained a maximum that approximated the 0.80 matching value. At the longer delays, the preference declined from the maximum. It was concluded that under two-key concurrent variable interval schedules of reinforcement, matching to the relative immediacy of reinforcement is of limited generality.

The implications for the present results for time allocation, interresponse time theories, the matching law, and concurrent chained schedules of reinforcement are discussed.

CHAPTER I

CONCURRENT OPERANTS

Despite its many forms over the years, one of the most durable tenets of psychology has been the law of effect. Thorndike (1949) stated it as follows: "...the immediate consequences of a mental connection (in particular, a satisfying state of affairs following a connection and belonging to it) can work back upon it to strengthen it..." A more current view of the law of effect is that a reinforcing event following a response of a given class (i.e., an operant) strengthens that response (e.g., Morse, 1966).

The strength of an operant can be measured in many ways, none of which is unequivocally the best in all situations. Examples of response strength measures are the probability of a response, rate of responding, amplitude of a response, latency of a response, resistance to extinction, and frequency of a response relative to the frequency of other responses (Herrnstein, 1970). The pervasive notion in response strength measures, however, is that reinforcement has an effect on responding in at least one measurable dimension.

The efficacy of a reinforcer is determined by several variables. For example, if food presentation is the putative reinforcement, its effectiveness may depend upon the deprivation level of the organism, the type of food, the delay of the

presentation after the response, the amount of food, and the schedule of food presentation. All of these kinds of variables may affect the efficacy of any reinforcer.

Many of the studies in the area of operant conditioning have been aimed at the effect of reinforcement on the strength of an operant. These studies have been extended to investigations of the effect of reinforcement on two or more operants at the same time, i.e., concurrent operants. This chapter will present a brief introduction to the study of concurrent operants.

Concurrent Schedules of Reinforcement

A schedule of reinforcement is a specification of the relations among reinforcement, time and responses (Morse, 1966). The most commonly studied schedules of reinforcement are the interval and ratio schedules with either fixed or variable parameters. Under a fixed-ratio (FR N) schedule, reinforcement follows the N-th occurrence of a response; under a variable-ratio (VR N) schedule, reinforcement follows the N-th occurrence of a response on the average. Under a fixed-interval (FI T) schedule, reinforcement follows the first occurrence of a response after time T (usually measured from the termination of the previous reinforcement); under a variable-interval (VI T) schedule, reinforcement follows the first occurrence of a response after time T on the average (Morse, 1966; Ferster and Skinner, 1957).

If two independent schedules of reinforcement are

simultaneously in effect, they are called concurrent schedules of reinforcement. Usually, in the experimental situation, each of the concurrent schedules of reinforcement controls the sequence of events on separate manipulanda (e.g., two keys in a pigeon operant-conditioning chamber). Under a two-key concurrent VI T VI T schedule, for example, reinforcement will follow a response according to the schedule associated with either key. The result is a doubling of the maximum rate of reinforcement that would be attainable on either key alone.

Generally, when two keys are equally available and responses on either key are reinforced, the pigeon will tend to respond on both keys. If a pigeon has been responding on one key (e.g., left) and switches to the other key (right), reinforcement might follow immediately the first response on the right key. The result of the reinforcement might be the strengthening of switching behavior *per se*. Although switching responses are observable and measurable, they may not be of direct experimental interest. A procedure termed *change over delay* (COD) is used to attenuate explicit reinforcement of this class of responses (Herrnstein, 1961; Herrnstein, 1970; Shull and Pliskoff, 1967). The COD prevents reinforcement of a response on one key if the response occurs sooner than some specified time (typically 1 or 1.5 sec) since the change from the other key.

Under two-key concurrent schedules of reinforcement,

responses on the two keys may be considered as different operants since the schedules of reinforcement are independent and since they occur on different manipulanda. In this context an appropriate and convenient measure of strength of an operant is the relative frequency of that operant. The relative frequency of an operant is the absolute frequency of that operant divided by the total frequency of both operants.

An experiment by Herrnstein (1961) provides an example of a two-key concurrent schedule of reinforcement and the use of relative frequency of responding as a dependent variable specifying response strength. The independent variable in this experiment was the proportion of reinforcements assigned to one of the two keys. Reinforcements were assigned according to independent VI schedules. The results showed that the pigeons' relative frequency of responding to the left key matched (i.e., equalled) the relative frequency (i.e., proportion) of reinforcements on that key (see Fig. 1). Algebraically,

$$\frac{P(l)}{P(l) + P(r)} = \frac{R(l)}{R(l) + R(r)}, \quad (1)$$

where P is the number of pecks (responses), R is the number of reinforcements, l is left and r is right.

The Matching Law

The matching law expresses that the relative frequency of a response matches the relative frequency of reinforcement for that response (Herrnstein, 1970; Herrnstein, 1974). One

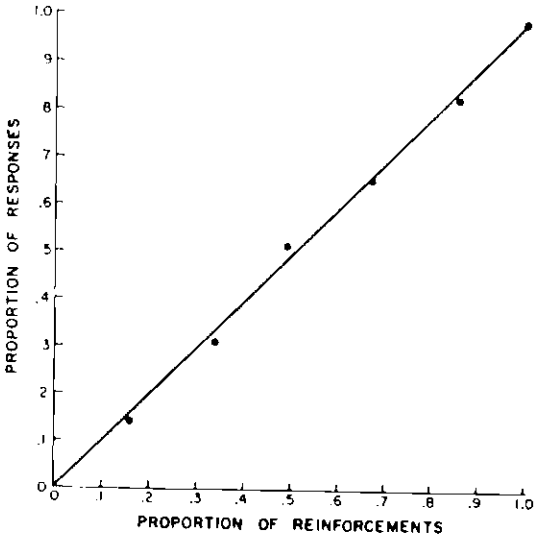


Figure 1. Proportion of Responses vs. Proportion of Reinforcements. (From Herrnstein, 1961; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

common form of the matching law is

$$\frac{P_1}{P_1 + P_2 + \ldots + P_N} = \frac{R_1}{R_1 + R_2 + \ldots + R_N}, \quad (2)$$

where P and R represent responses (e.g., key pecks) and reinforcements, respectively, for some time interval and the subscripts indicate which reinforcements are correlated with which responses.

Equation 1 which expressed the matching for two operants can be derived from equation 2 (Herrnstein, 1974):

$$P_1 = \frac{R_1 \Sigma P_i}{\Sigma R_i} \qquad P_2 = \frac{R_2 \Sigma P_i}{\Sigma R_i}$$

$$\frac{P_1}{P_1 + P_2} = \frac{R_1 \Sigma P_i}{\Sigma R_i} \Bigg/ \left(\frac{R_1 \Sigma P_i}{\Sigma R_i} + \frac{R_2 \Sigma P_i}{\Sigma R_i} \right)$$

$$\frac{P_1}{P_1 + P_2} = \frac{R_1}{R_1 + R_2}$$

Thus, for any two response alternatives, the relative frequency of one with respect to the sum of the two matches the relative frequency of reinforcement for that response with respect to the reinforcements for both.

Data resulting from several studies can be subsumed under the matching law (Herrnstein, 1970): 1. Reynolds (1963) demonstrated that matching occurred with three response alternatives. 2. Holz (1968) found that responding matched the distribution of reinforcements even though each response was punished by electric shock. 3. Catania (1963) and Neuringer

(1967) found that the relative frequency of a response matched the relative magnitude of reinforcement for that response when reinforcement frequency was equated for the two responses. 4. Shull and Pliskoff (1967) also demonstrated matching of relative frequency of responding to the relative frequency of reinforcement using rats as subjects, intracranial stimulation as reinforcement, and various COD values. 5. Brownstein and Pliskoff (1968) used a different response, i.e., position in the test chamber, and found matching.

One type of experimental procedure that is an exception to the matching law is probability learning (Herrnstein, 1970). In this procedure two stimuli are used with reinforcers assigned to them on a random basis with some specified probability. That is, the probability of reinforcement of a response to a given stimulus is predetermined and administered in a random fashion to prevent the learning of sequential dependencies (Warren, 1965). For example, if the stimuli are red and green with probabilities of reinforcement of 0.4 and 0.1, respectively, two types of responding may result. The first is called maximization; the organism in this case would respond exclusively to the stimulus with the higher probability of reinforcement (therefore, in this example, the red stimulus would be the exclusive choice). The other type of responding is matching the probability; 80 of 100 responses would be made to the red stimulus and 20 responses to the green stimulus (i.e., the ratio of responses matches the ratio

of the reinforcement probabilities (Herrnstein, 1970; Warren, 1965)). In the case of maximization, obviously the relative frequency of responding does not match the relative frequency of reinforcement in more than a trivial manner. In the case of probability matching, the relative frequency of responding does not match the relative frequency of reinforcement. In the example above, with probabilities of reinforcement of 0.4 and 0.1, the relative frequency of responding to the red (0.4) stimulus is 0.8 (i.e., 80/80+20); but the relative frequency of reinforcement to the red stimulus is 32/34 (i.e., (80X0.4)/(80X0.4) + (20X0.1)). As Herrnstein (1970) pointed out, however, there is a very important procedural difference: probability learning experiments are typically discrete-trial experiments in which the frequency of a response is not of great interest. To obtain the maximum rate of reinforcement, the maximization-type responding is required. In the free-operant experiment in which frequency of responding is of interest (e.g., Herrnstein, 1961), reinforcement frequency is maximized by responding to both keys.

CHAPTER II

DELAY OF REINFORCEMENT

Another reinforcement parameter that seems capable of producing matching behavior is delay of reinforcement. As mentioned before, delay of reinforcement is a variable that affects the potency of a reinforcer; the longer the delay, the less effective the reinforcer in strengthening or maintaining responding.

Effects of Delayed Reinforcement

Anderson (1932) allowed albino rats to enter one of four compartments where they were detained either one, two, three, or four minutes before they were given access to food. The data showed that the albino rats went into the short delay compartment at a much higher frequency than would be expected by chance. However, the rats did not choose the short delay compartment exclusively.

Perin (1943) studied the effectiveness of reinforcement as a function of the delay of reinforcement. Albino rats were trained to eat from a food magazine in a test chamber; then food was only presented after a lever-press response. The five groups of subjects were reinforced with delays of 0, 2, 5, 10, and 30 sec. Perin then plotted the latency of response (time from access to lever until response) against

trials for each group. The latency decreased over trials for all groups with the exception of the 30-sec group. Also, latencies decreased faster and to lower values for the shorter-delay groups.

Hull (1943), after reviewing the relevant literature on the delay of reinforcement, proposed the following:

> The maximum habit strength (m') attainable with a given amount and quality of reinforcement closely approximates a negative growth function of the time (t) separating the reaction from the reinforcing state of affairs; the asymptote or limit of fall of this gradient is zero;...
>
> The shorter the delay of reinforcement, the steeper becomes the rise of the associated curve of learning.
>
> With training, organisms tend to choose that one of a pair of alternatives which yields reinforcement with the lesser delay
>
> The preference for that one of a pair of acts involving the lesser delay in reinforcement is attained gradually as training increases. (Hull, 1943, p. 145-151)

Ferster (1953), using a free-operant procedure, found that when reinforcement was delayed for 60 seconds following stable performance with immediate reinforcement, the rate of responding declined as would be found in extinction. However, when the delay was increased gradually from 1 to 60 seconds, the response rate did not decrease. Thus, with proper training procedures, the effect of delay of reinforcement can be minimized or eliminated for a single operant. Nevin (1974) obtained a similar result: response rate was relatively insensitive to delay of reinforcement which ranged from 1 to 10 seconds.

Concurrent Schedules and Delays of Reinforcement

Chung (1965) studied the effects of delay of reinforcement on the relative frequency of responding using a two-key concurrent schedule with each key associated with a VI 1-minute schedule of food reinforcement. On one key reinforcement was always immediate (no delay); on the other key reinforcement was delayed. The value of the delay was changed over several conditions and ranged from 0 to 28 seconds. During the delay of reinforcement period, the house lights and key lights were turned off and key pecks had no scheduled consequences.

Under these conditions, the maximum rate of reinforcement on the delay key decreases as the value of the delay increases. So Chung scheduled a blackout on the no-delay key in order to equate the maximum rates of reinforcement on the two keys. The blackouts on the no-delay key were scheduled on an independent VI 1-min schedule. If the blackout and reinforcer were assigned at the same time, the first response produced the reinforcement and the second response produced the blackout; thus, blackout and reinforcement were never paired on the no-delay key. Figure 2 shows the relative frequency of responding on the delay key as a function of the delay. The exponential function that was fit to the data would be expected from the earlier studies and Hull's postulates mentioned above. However, Chung (1965) said that

> ...the difference between the parameters of the present

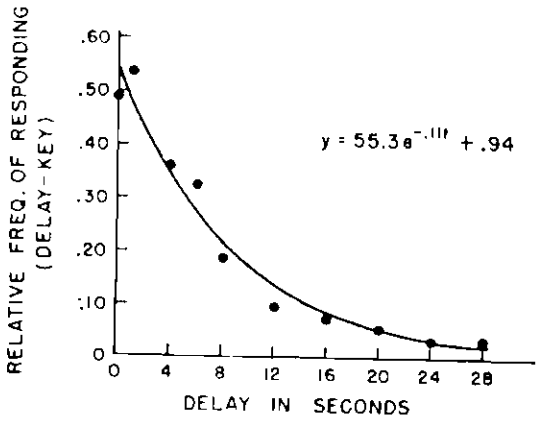


Figure 2. Relative Frequency of Responding vs. Delay. (From Chung, 1965; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

> study and those predicted by Hull, and the unspecified relation between habit strength and the dependent variable examined here, make it difficult to assert that the present findings confirm Hull's preduction.

Chung (1965) also found that the total rate of responding (total number of responses on both keys divided by the session duration) remained constant over the conditions, but the absolute rate of responding on the delay key (number of responses on delay key divided by session duration) decreased exponentially as did the relative frequency of responding (Fig. 3). This similarity of absolute and relative response rates might be taken as evidence for their being measures of the same variable, namely response strength. Furthermore, since the total response rate remained constant for all values (which changed maximum reinforcement frequency from one to two per minute), interpolated blackouts did not affect the performance on VI responding (Chung, 1965).

Chung and Herrnstein (1967), with a few alterations, extended the experiment by Chung (1965). The pigeons were placed in a two-key (with a 1-sec COD to prevent reinforcement of switching). The left key, called the standard key, had an 8-sec delay of reinforcement for one group and a 16-sec delay of reinforcement for a second group. On the right key, called the experimental key, the delays ranged from 1 to 30 sec in different conditions (2 to 30 sec for the second group). Additional blackouts were not scheduled to equate the maximum rates of reinforcement as in Chung (1965). The relative frequency of responding on the experimental key as

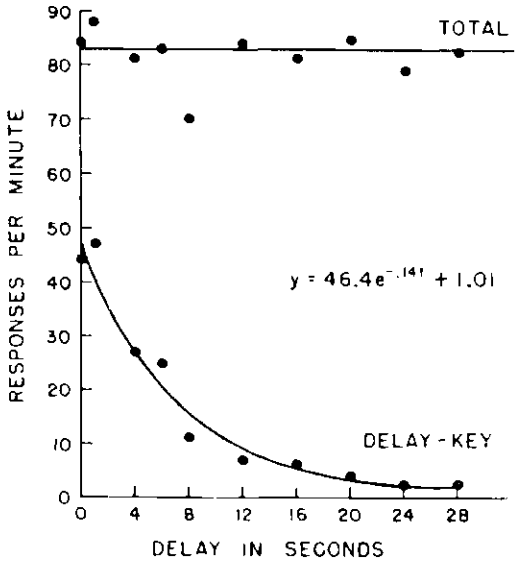


Figure 3. Responses Per Minute vs. Delay. (From Chung, 1965; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

a function of the delays is shown in Fig. 4. The relative frequency of responding to the experimental key declined as it did in Chung (1965) (shown in the lower curve). Chung and Herrnstein (1967) then plotted the relative frequency of responding on the standard key as a function of the relative delay of reinforcement on the experimental key (Fig. 5), where the relative delay of reinforcement is

$$d(e) \;/\; (d(e) + d(s)). \qquad (4)$$

In equation 4, d is the delay in seconds and the subscripts e and s indicate the experimental and standard keys, respectively. The similarity of Fig. 5 to the matching function is striking. In fact, if the delay in equation 4 is replaced by immediacy (reciprocal of delay) to get a direct relationship rather than an inverse relationship, the familiar matching function is obtained (Chung and Herrnstein, 1967). Thus, the relative frequency of responding to the experimental key matched the relative immediacy of reinforcement on the experimental key:

$$\frac{P(e)}{P(e) + P(s)} = \frac{I(e)}{I(e) + I(s)}, \qquad (5)$$

where P is key pecks, I is the reciprocal of delay of reinforcement and the subscripts e and s indicate experimental and standard key, respectively.

Chung's data (1965) in the lower curve of Fig. 4 show a slight increase in the relative frequency of responding on the experimental key at 1.0 sec delay of reinforcement. This

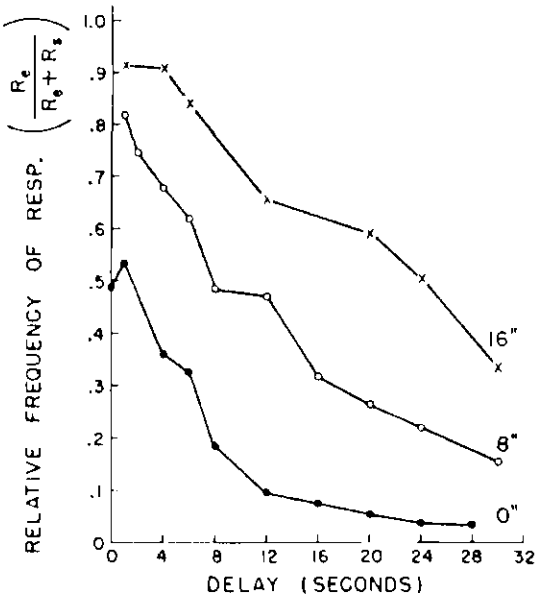


Figure 4. Relative Frequency of Responding vs. Delay. (From Chung and Herrnstein, 1967; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

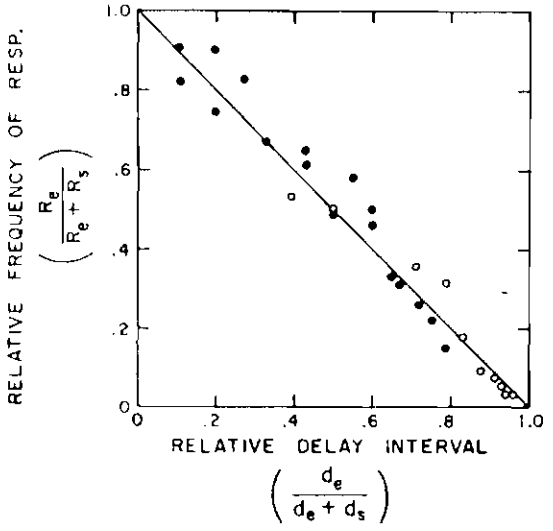


Figure 5. Relative Frequency of Responding vs. Relative Delay. (From Chung and Herrnstein, 1967; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

increase was interpreted by Chung and Herrnstein (1967) as showing a slightly stronger response when reinforcement was delayed for a short period than when reinforcement was immediate. A tenable explanation for this datum is that when the feeder presentation immediately followed the key peck, some portion of the access time to grain was lost while the pigeon moved from the feeder. This loss in access to the feeder resulted in reinforcement of a lower magnitude compared to the reinforcement that was slightly delayed. Thus, feeder presentation was a more potent reinforcement if delayed for a short time since the magnitude of reinforcement was decreased by immediate presentation of grain. From the lower curve in Fig. 4 the relative frequency of responding on the experimental key would be 0.5 (equal responding on both keys) at approximately 1.6 seconds delay on the experimental key. It can be inferred, therefore, that the potencies of the two reinforcers are equal: a reinforcement delayed 1.6 seconds is equivalent to immediate reinforcement with decreased magnitude. It does not mean that it takes 1.6 seconds for a pigeon to get to the grain from a key.

By substituting the delayed reinforcement equivalence for immediate reinforcement, Chung's data (1965) were incorporated into the matching equation (Eq 5); i.e., I(s) was set equal to 1/1.6. The open circles in Fig. 5 represent Chung's data (1965). In the following discussions, "nominal delay" will refer to the delay as it is actually scheduled and

"functional delay" will refer to the assumed delay between the reinforced response and reinforcement.

As it was mentioned above, Chung and Herrnstein (1967) did not schedule blackouts on the shorter delay key to equate the maximum rates of reinforcement. Also, the obtained rates of reinforcement were dependent on the subjects' behavior (because of the two independent schedules of reinforcement). Thus, the relative frequency of reinforcement that was obtained on the experimental key was not always 0.50. Figure 6 shows the relative frequency of responding on the experimental key as a function of the relative frequency of reinforcements for that key (including those values calculated from Chung (1965)).

Since Chung (1965) and Chung and Herrnstein (1967) did not equate the relative frequency of reinforcement for the two keys and since Chung and Herrnstein (1967) did not equate the maximum rates of reinforcement, it is not clear that their results were due to delay of reinforcement alone. Herbert (1970) noted the confounding of delay and reinforcement frequency and designed an experiment to eliminate the effects of reinforcement frequency. Whereas Chung (1965) and Chung and Herrnstein (1967) used two independent VI schedules, Herbert (1970) used one VI schedule that assigned reinforcers to each key with equal probability and on a random basis.

Herbert's procedure (1970) was suggested by the results of an experiment by Shimp (1969, Exp II). Shimp (1969), for

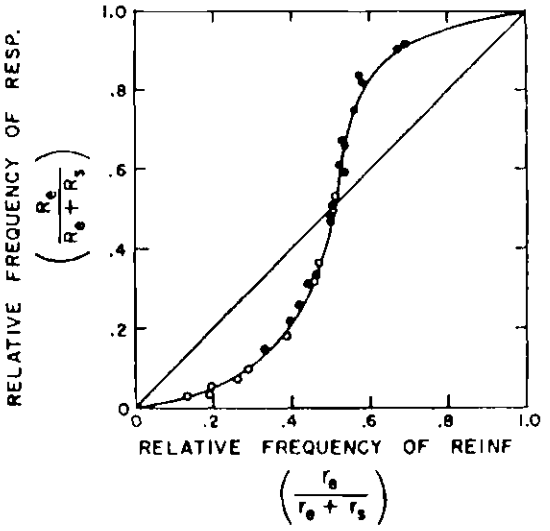


Figure 6. Relative Frequency of Responding vs. Relative Frequency of Reinforcement. (From Chung and Herrnstein, 1967; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

reasons which will become evident in the next chapter on interresponse-time theories, wanted to know if making reinforcement response-dependent after the delay (or blackout) would alter matching to the relative immediacy of reinforcement. Shimp used the Chung and Herrnstein (1967) procedure with two exceptions: after the delay of reinforcement another response was required on the same key to operate the feeder and reinforcements were equated on the two keys. The results indicated that matching to the relative immediacy of reinforcement will occur with the additional requirement of a response after the delay. Thus, the role of the blackout in delays was uncertain.

Herbert (1970) subsequently investigated the role of blackouts in the matching of responding to the relative immediacy of reinforcement. In Exp I she programmed a blackout after each response on both keys. If the VI schedule had assigned reinforcement to a key, the next response on that key produced a blackout which was then immediately followed by the feeder operation. The three conditions had blackouts of 8 and 8 sec, 2 and 8 sec, and 18 and 8 sec. The relative frequency of responding matched the relative immediacy of reinforcement. In the second experiment, each response produced a blackout except for the response that produced food presentation. Thus, this procedure was the same as Shimp's (1969) Exp II with the addition of a blackout after each response. Again, matching was found.

In the third experiment, Herbert (1970) replicated the Chung (1965) procedure with the additional restriction of equalizing reinforcements on the two keys. It will be recalled that Chung (1965) used two VI schedules that operated independently for the two keys. On one key reinforcement followed immediately (nominally) and on the other key reinforcement followed delays of 0, 1, 4, 6, 8, 12, 16, 20, 24, and 28 sec. Herbert (1970, Exp III) used delays of 0, 0.2, 0.5, 1, 3, 5, and 15 sec for the delay key. She then used the procedure that was suggested by Chung and Herrnstein (1967) in analyzing her data; i.e., the nominally immediate reinforcement was assumed to have a functional delay of 1.6 sec. The relative immediacies were calculated by equation 5 with I(s) set equal to 1/1.6. Figure 7 shows the results as Herbert plotted them. From this figure it would appear that matching of relative frequency of responding to the relative immediacy of reinforcement did not occur. Herbert (1970) concluded that if responding on the two keys had the same consequences, matching would occur (as in Exps I and II); otherwise, it will not (as in Exp III).

There is a logical flaw in Herbert's analysis of Exp III (1970). In Fig. 7 the greatest deviations from matching occur at relative immediacies of reinforcement exceeding the value of 0.50. But these values imply that nominally delayed reinforcement was more immediate than nominally immediate reinforcement. When the delay values were less than 1.6 sec

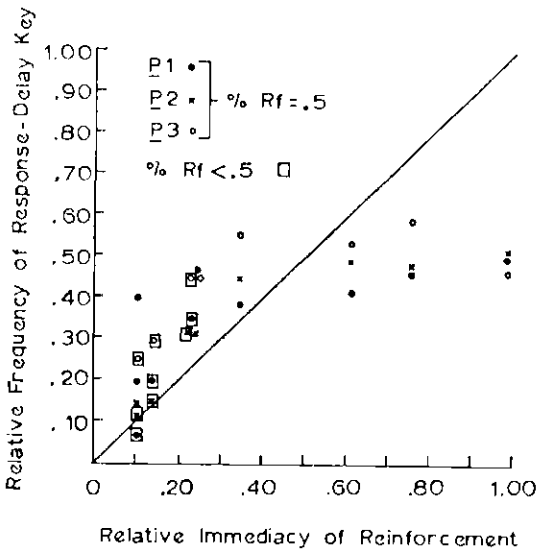


Figure 7. Relative Frequency of Responses vs. Relative Immediacy of Reinforcement. (From Herbert, 1970; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

(0, 0.2, 0.5, and 1), it must be assumed that their functional delays were also equal to 1.6 sec. Those conditions which she plotted as relative immediacies greater than 0.50 should be plotted as being equal to 0.50. Also in Fig. 7, one condition was apparently deleted and one misplotted. A corrected plot of Herbert's data is shown in Fig. 8. The mistake of having nominally delayed reinforcement more immediate than nominally immediate reinforcement also appeared in Chung and Herrnstein's Fig. 5 (1967), as they plotted Chung's data with one value of relative delay of less than 0.50.

The lack of fit of Herbert's (1970) data to matching at the relative immediacies of reinforcement of less than 0.50 can be questioned on the basis of the constant 1.6 sec delay that was used. If a higher value of delay is assumed to operate on the nominally immediate reinforcement, the points in Fig. 8 would shift toward a closer fit with the matching function. Figure 9 shows Herbert's data replotted with 2.6 sec as the assumed delay for the nominally immediate reinforcement. From Fig. 9 it must be concluded that Herbert's Exp III (1970) is not a counter-example of matching to the relative immediacy of reinforcement.

Summary

To summarize choice and delay of reinforcement experiments, it has been found that if responding on one key leads to immediate reinforcement and responding on another key leads

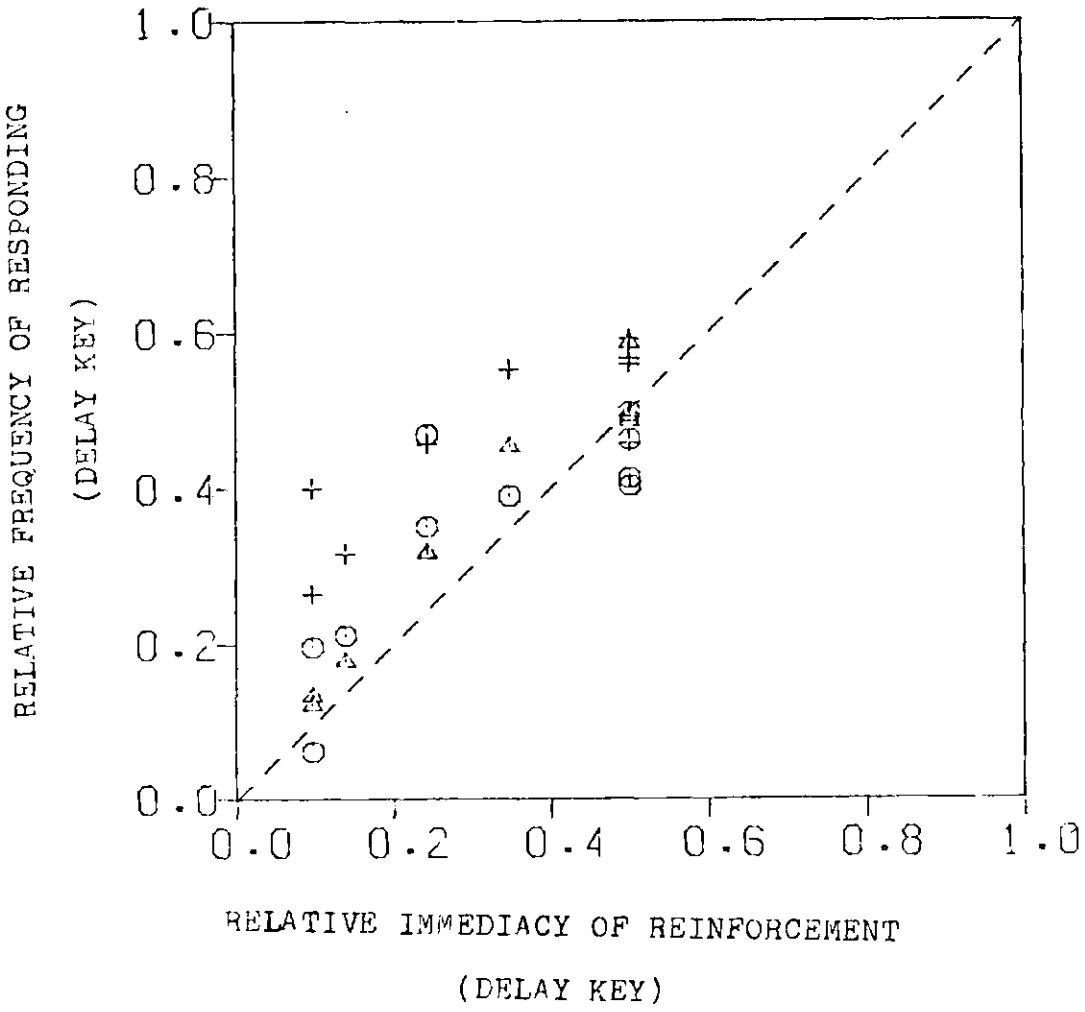


Figure 8. Relative Frequency of Responses vs. Relative Immediacy of Reinforcement. (This figure is a corrected plot of Herbert's (1970, Experiment III) data. The original plot is shown in Figure 7.)

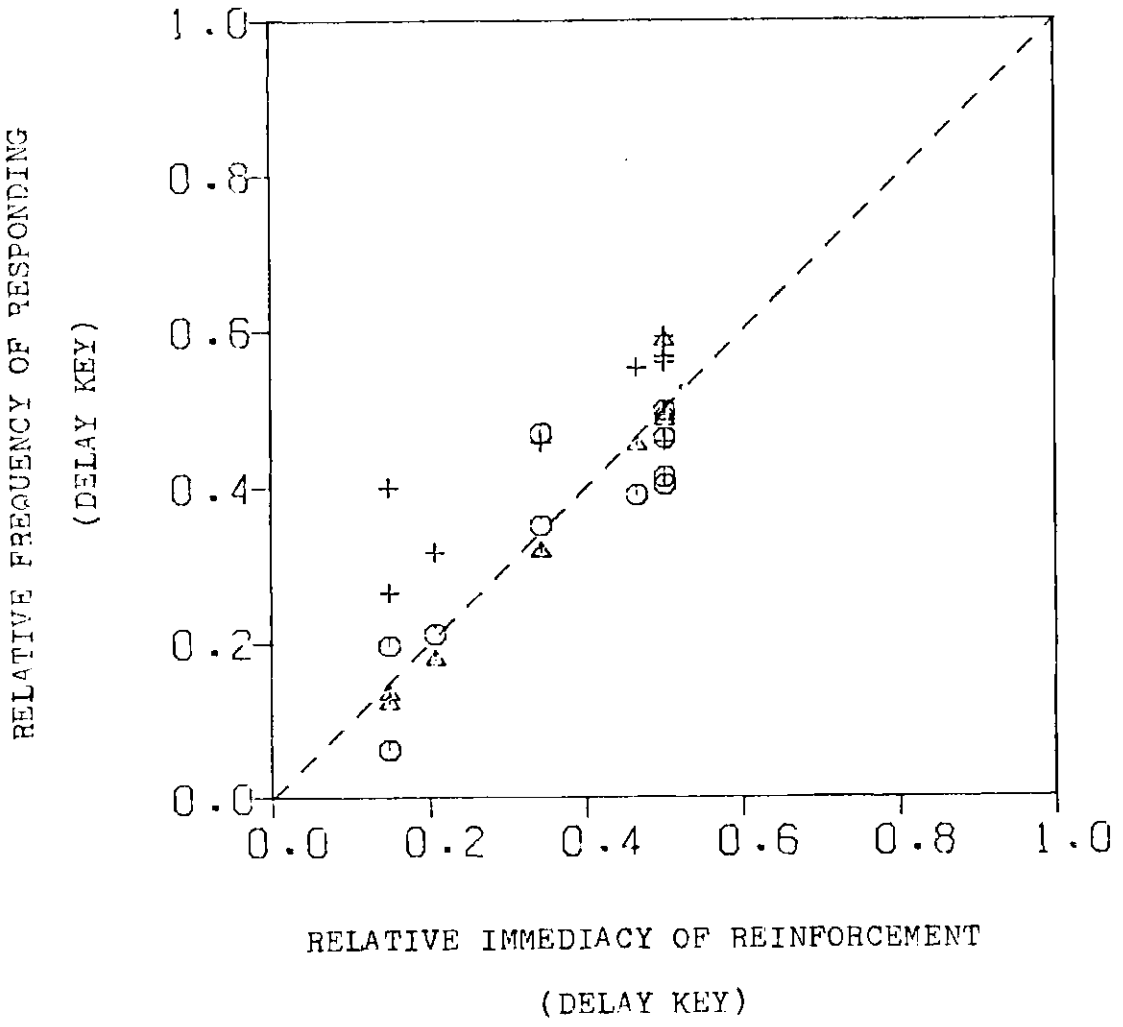


Figure 9. Relative Frequency of Responding vs. Relative Immediacy of Reinforcement. (This figure is the same as Figure 8 except that the functional delay was assumed to be 2.6 seconds (in Figure 8 the functional delay was taken as 1.6 seconds).)

to delayed reinforcement, either the relative frequency of responding on the delay key decreases exponentially with increasing delays (Chung, 1965), or the relative frequency of responding on the delay key matches the relative immediacy of reinforcement when a functional delay is assumed for the nominally immediate reinforcement (Chung and Herrnstein, 1967; Herbert, 1970). If both keys have delayed reinforcers scheduled on them, then the relative frequency of responding on one key matches the relative immediacy of reinforcement on that key (Chung and Herrnstein, 1967), even if an additional response is required after the delay interval has expired (Shimp, 1969, Exp II; Herbert, 1970, Exp II).

The problem of relative frequency of responding on a delay key when the other key provides immediate reinforcement cannot be solved with present data; i.e., does the relative frequency of responding on the delay key decrease exponentially (Chung, 1965; Hull, 1943) or does the relative frequency of responding on the delay key match the relative immediacy of reinforcement by assuming a functional delay for the nominally immediate reinforcement (i.e., linear function) (Chung and Herrnstein, 1967)? Without going into a great amount of detail on this problem, it can be seen that the two functions (exponential and linear) are mathematically incompatible (Chung and Herrnstein, 1967). A possible method of attacking this problem would be to use rats with intracranial stimulation as the reinforcer. Intracranial stimulation

(ICS; electrical stimulation through chronically implanted electrodes in the posterior region of the hypothalamus) would provide reinforcement with temporal parameters independent of the organism's behavior: the functional delay is exactly the nominal delay. A delay of reinforcement experiment using ICS was conducted by Keesey (1964). He found that the acquisition rate of a brightness discrimination by rats was exponentially related to the delay of reinforcement.

When both keys have delays of reinforcement programmed on them, the matching function is a tenable description of the distribution of responding between them (Chung and Herrnstein, 1967; Shimp, 1969, Exp II; Herbert, 1970, Exps I and II). However, the range of delays that have been used is rather small, the longest combination being 16 and 30 sec on the two keys. The actual values of the delays may be important as well as the ratio of delays. Kimble (1961) pointed this out in a discussion of maze learning experiments where maze alley length was equated with delay of reinforcement.

CHAPTER III

INTERRESPONSE-TIME THEORIES OF RESPONDING

As mentioned above, Herrnstein (1961) found matching of relative frequency of responding to relative frequency of reinforcement on two keys; Catania (1963) and Neuringer (1967) found that relative frequency of responding matched relative magnitude of reinforcement. Shimp (1968) studied whether these relationships applied equally well to concurrently scheduled paced VI, paced VI schedules of food reinforcement. The paced VI schedule provides a tool for the study of interresponse times (IRTs).

Interresponse time (IRT), like delay of reinforcement, is a temporal variable involved in the response-reinforcement relationship. IRT in its simplest definition is the time that elapses between successive responses. However, there are three distinguishable views that extend the above definition: IRT as a stimulus, IRT as a property of a response, and IRT as an operant.

IRT as a Stimulus

Anger (1956) investigated the frequency of IRTs in class intervals (i.e., the number of responses that terminate IRTs within certain bounds of time). Specifically, Anger looked at the distribution of IRTs on a VI schedule of food

reinforcement as a function of exposure to the schedule. Then Anger selectively reinforced long IRTs on a VI schedule to determine how the distribution of IRTs changed. Anger found that reinforcements per IRT class exerted little control on the distribution of IRTs, but there was a relationship between the IRT distribution and reinforcements per hour. Anger used the IRT per opportunity (IRT/OP) statistic rather than the relative frequency of IRTs, because the former proved to be a more sensitive measure of the effects of reinforcement frequency than the latter. This greater sensitivity was attributed to the fact that the emission of a response terminating an IRT removes the possibility of a longer IRT while shorter IRTs had the opportunity to occur. The use of the IRT/OP statistic implies that the IRT is a stimulus to which a response is emitted or not emitted. Longer IRTs occur less frequently because the organism has fewer opportunities to respond to them.

IRT as a Response Property

Morse (1966) presented another view of the IRT -- the IRT as a property of the response that terminates it. Morse further proposed a descriptive theory of responding on interval schedules. It was based on the fact that the longer the time since the last response the greater the probability of the next response being reinforced. The probability of reinforcement also increases with the sum of IRTs for all previous responses since the last reinforcement. However, Morse listed

several drawbacks to this behavioral model, e.g., there is no evidence that slight differences in the probability of reinforcement can exert control on responding and associated IRTs.

IRT as an Operant

Shimp in a long sequence of experiments (1967, 1968, 1969, 1970, 1971, 1973a, 1973b, 1974; Moffit and Shimp, 1971; Hawkes and Shimp, 1974), has provided some evidence that the IRT may be considered as an operant, the same as any free operant. The essence of Shimp's work has been to show that responding on a VI schedule is a function of the reinforcement frequency of different IRT classes. The paced VI schedule of reinforcement has been the major tool to demonstrate this possibility. A paced VI schedule specifies that reinforcement will follow the first response after some variable time averaging T min has elapsed, if, and only if, the response terminates an IRT in a specified class. An example of a pacing dependency might be paced VI 1-min (IRT between 1 and 2 sec): the first response occurring after an average time of 1 min has elapsed, and that occurs at least 1 sec since the last response, but no more than 2 sec since the last response, will be reinforced; i.e., IRTs between 1 and 2 sec are reinforced on a VI 1-min schedule.

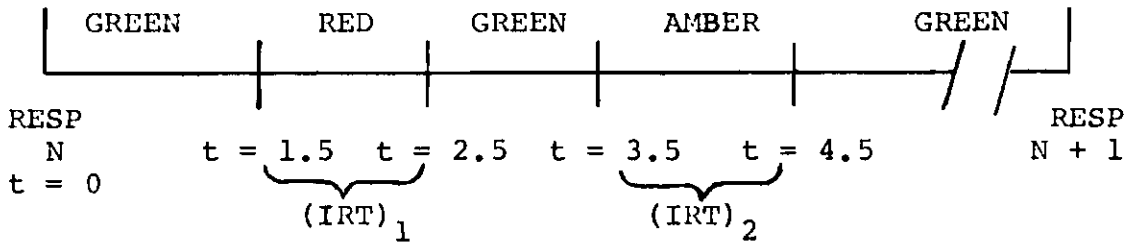
If the schedule presents reinforcement after a response in either of two IRT classes, then the schedule would be a concurrent paced VI, paced VI schedule of reinforcement. It

follows then that a VI schedule of reinforcement might be considered to comprise many concurrently scheduled paced VI schedules, only the pacing dependencies are not specified but rather result from the organism's behavior.

To study the relationship between reinforcement and the IRT distribution, the interaction of the organism's behavior with the distribution of reinforcements and IRTs must be eliminated. Therefore, Shimp has worked almost exclusively with pacing dependencies; however, the notion of concurrent operants has been retained by manipulating the frequency of reinforcement of the two or more IRT classes (Shimp, 1967), and showing that various functional relationships hold which bear relationship to those already demonstrated by more conventional concurrent schedules.

Shimp (1968) then applied the variables that were studied by Herrnstein (1961), i.e. relative frequency of reinforcement, and by Catania (1963) and Neuringer (1967), i.e. relative magnitude of reinforcement, to concurrently scheduled paced VI, paced VI schedules of reinforcement. Specifically, reinforcement was available only for IRTs in the classes 1.5 to 2.5 and 3.5 to 4.5 sec; responses that terminated IRTs that were not in these two classes were never reinforced. The two classes of IRTs which might be reinforced were each associated with a distinct key light (i.e., discriminative stimulus). Thus, a sequence of lights for the key might be green for 1.5 sec after a response; then red

for 1 sec (associated with the first IRT class); then green for 1 sec; then amber for 1 sec (associated with the second IRT class); and finally green until a response is made (see diagram below). The sequence of key lights starts over whenever a response is made.



In order to determine the effects of relative frequency of reinforcement and relative magnitude of reinforcement on the relative frequency of responses terminating IRTs in the shorter class, Shimp varied each in different conditions. The probability of a reinforcer being assigned to the short IRT class (and therefore the relative frequency of reinforcement over many reinforcements) was varied from 0.2 to 0.85. The relative magnitude of reinforcement (duration of access to food in the short-IRT class divided by the sum for both classes) was varied from 0.2 to 0.8. A third parameter, relative access to food, incorporated both the relative frequency and relative magnitude of reinforcement. Shimp found that the relative frequency of short IRTs was an increasing, negatively accelerated function of the relative frequency of reinforcement and relative magnitude of reinforcement; however, even at low values of the independent

variables, the short IRT was preferred. Of greater interest from the data in this experiment was the function relating relative frequency of short IRTs to the relative access to food. The least squares fit to the data passed through the points (1, 1) and (0.5, 0.699). That is, if all the reinforcements were for the short IRTs, all responses would be in the short IRT class; when reinforcements were equal for both IRT classes, the shorter IRTs occurred 69.9% of the time.

The importance of these results is best understood by recalling the results of Chung and Herrnstein (1967). They found that if the relative frequency of responding on the experimental key matched the relative immediacy of reinforcement on that key (immediacy being the reciprocal of delay),

$$\frac{R(e)}{R(e) + R(s)} = \frac{I(e)}{I(e) + I(s)} .$$

Shimp (1968) reasoned that if the emission of one of two IRTs is equivalent to the emission of a response on one of two keys, then the duration of the IRT is directly analogous to the delay of reinforcement. This analogy would lead to the prediction that the relative frequency of the short IRTs would match the relative immediacy of reinforcement. Using the midpoints of the two IRT classes (2 and 4 sec), the relative reciprocal of the short IRT is 0.667:

$$\frac{1/2}{1/2 + 1/4} = 0.667 .$$

The closeness of the two values (0.667 and 0.699) led Shimp

to pursue the question, "Does an IRT x-sec long have the properties of an x-sec delay of reinforcement?" (Shimp, 1969, p. 403).

Shimp (1969) varied the relative reciprocal of the length of the IRT class associated with a red key light from 0.138 to 0.887 (i.e., the red light was associated with both the long and short IRT classes over conditions). He found that the relative frequency of responding to the red stimulus matched the relative reciprocal of the IRT duration. These results are shown in Fig. 10. Clearly, these data indicated that IRTs might be considered as emitted operants since the predicted values from Chung and Herrnstein (1967) were found. The only procedural difference that remained was that in the Chung and Herrnstein (1967) experiment no response was required after the delay to obtain reinforcement, while in the present analogy a response was required after the "delay". Shimp (1969, Exp II) then replicated some points from Chung and Herrnstein's experiment with the additional requirement of a response after the delay was over. The results, which were discussed in the preceding chapter, were that relative frequency of responding matched the relative immediacy of reinforcement.

This impressive demonstration of the two IRT classes being directly analogous to two-key concurrent operants represented a potentially great advance toward a theory of IRT responding. Reynolds and McLeod (1970) presented a very

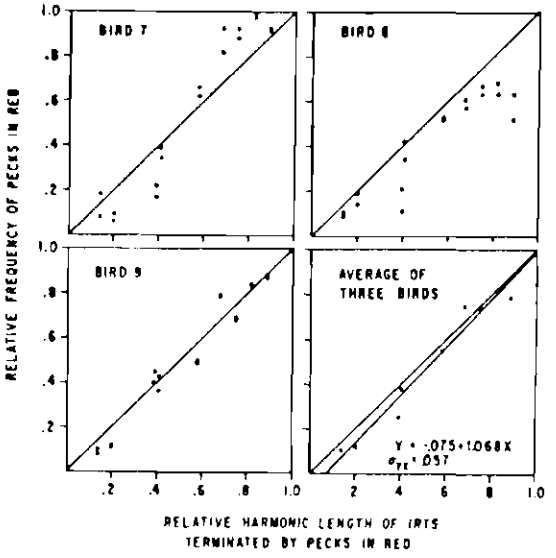


Figure 10. Relative Frequency of Pecks in Red vs. Relative Harmonic Length of IRTs Terminated by Pecks in Red. (From Shimp, 1969; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

eloquent statement on the need for such a theory:

> ...from a single set of statements describing how the reinforcement of IRTs determines their frequency of occurrence, the hope has been to account for the changes that take place when an organism is first exposed to a schedule, as well as for the characteristics of the performance maintained by the schedule in steady state. From a single mechanism, the results of hundreds of experimental findings might be derived (Reynolds and McLeod, 1970, p. 88).

Shimp then proceeded to investigate the generalities of his findings. Using the two discriminated IRT classes on a single key (as in Shimp, 1968 and 1969) under a VI schedule of reinforcement, Shimp (1970) studied the effects of rate of reinforcement (reinforcements per hour). The relative frequency and relative magnitude of reinforcement were the same for both IRT classes. The VI parameter was varied from 20 seconds to 18 minutes. The results showed that matching was a special case of the reinforcements-per-hour function. Figure 11 shows that matching was obtained only above 30 to 40 reinforcements per hour (dotted line in lower right panel). At lower reinforcement densities the choice appeared to be unpredictable. Therefore, two variables were known to affect the relative frequency of an IRT and its relationship with the relative rate of reinforcement: the relative reciprocal of its duration and the absolute reinforcement rate.

Hawkes and Shimp (1974) asked if the absolute rate of responding also affected the relationship between the relative frequency of an IRT and the relative frequency of its reinforcement. The rate of responding on paced VI schedules

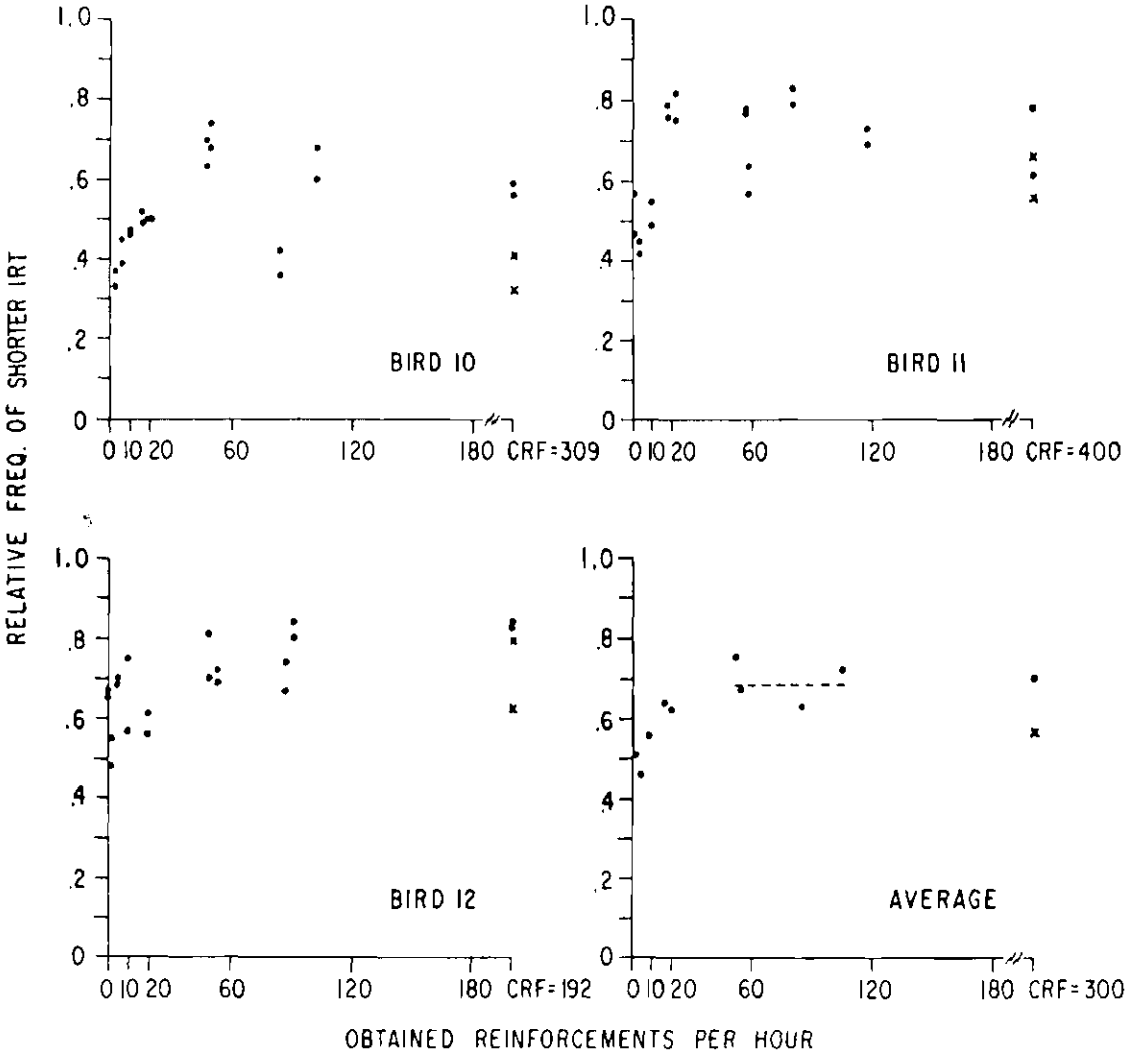


Figure 11. Relative Frequency of Short IRT vs. Obtained Reinforcements Per Hour. (From Shimp, 1970; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

is inversely related to the duration of the IRT requirement -- the longer the duration of the reinforced IRT classes, the lower the response rate. Hawkes and Shimp (1974) held the relative reciprocal of the short IRT constant at 0.70 and varied the upper and lower bounds of the two IRT classes to obtain different response rates. Figure 12 shows that matching was obtained at a certain range of lower bounds for the short IRT. At high rates of responding, neither of the two IRT classes was more preferred. Again, matching appeared to be a special case of another function, rate of responding.

Summary

Shimp (1968) found that an IRT can be considered as an operant like any other response, in that the relative frequency of an IRT varied as a function of the reinforcement parameters known to affect concurrent responding. However, the temporal parameters of the IRTs were superimposed on these functions, since the shorter IRT was more preferred (Shimp, 1968). By using the analogy of an IRT being equivalent to a delay of reinforcement, Shimp (1969) found that the relative frequency of an IRT matched the relative reciprocal of the short IRT (which is analogous to Chung and Herrnstein's (1967) matching to the relative immediacy of reinforcement).

However, Shimp (1970) found this relation to be a special case of the rate of reinforcement function: with fewer than 30 reinforcements per hour, matching was not found. It will be recalled that in the experiment by Chung and

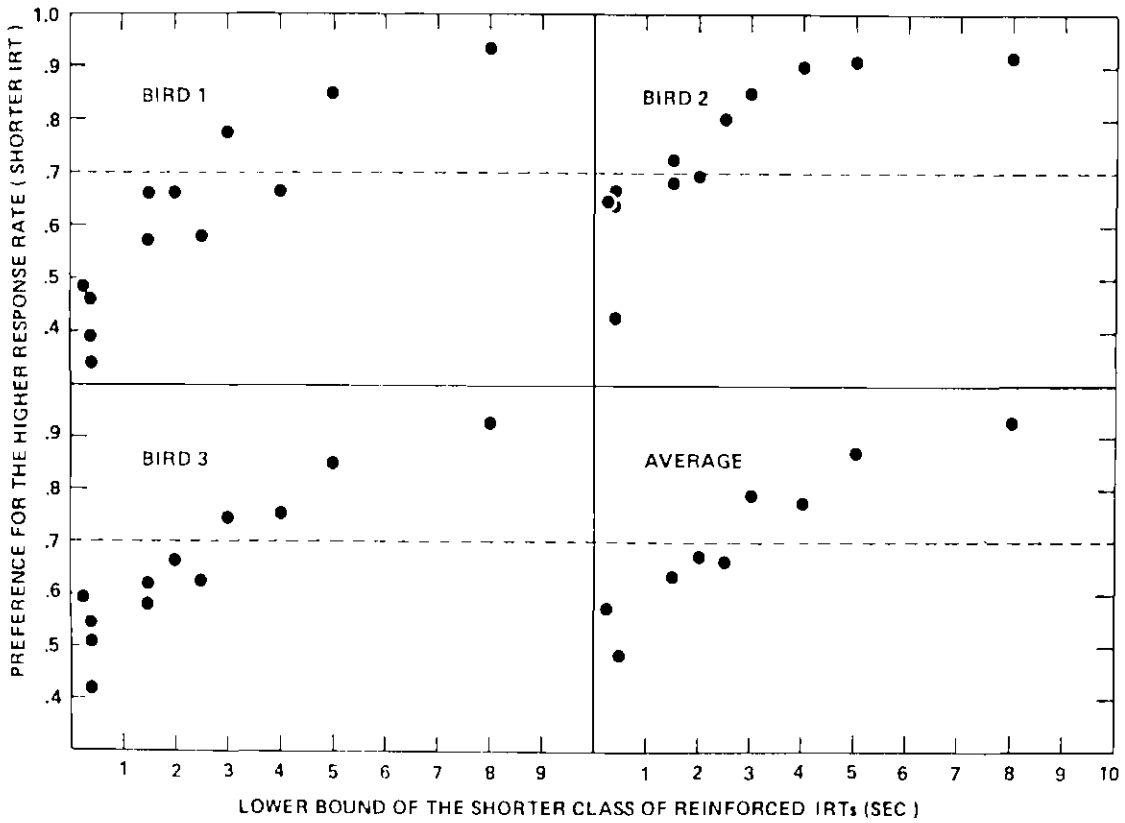


Figure 12. Preference for the Higher Response Rate vs. Lower Bound of the Shorter Class of Reinforced IRTs. (From Hawkes and Shimp, 1974; reproduced by permission from the Society for the Experimental Analysis of Behavior, Inc.)

Herrnstein (1967, the maximum rate of reinforcement was 120 per hour (concurrent VI 1 min, VI 1 min). Therefore, it is questionable whether their results are valid for the reinforcement densities used in the study by Shimp (1970). If matching as obtained by Chung and Herrnstein (1967) were to hold at low reinforcement densities, then it may indicate that an IRT cannot be considered as an operant in the same sense that a response on one of two keys is an operant.

Hawkes and Shimp (1974) found another variable that affects the IRT matching function -- absolute rate of responding. At high response rates (short IRTs) there was little preference; at low response rates (long IRTs), the preference for the short IRT exceeded the matching value. The response rate in the Hawkes and Shimp (1974) study is analogous to the delays of reinforcement for Chung and Herrnstein (1967); high response rates are analogous to short delays and low response rates are analogous to long delays. Again, it is questionable whether matching to relative immediacy of reinforcement, as postulated by Chung and Herrnstein (1967), would hold for a large range of delays.

Thus, in limited ranges of reinforcements per hour (Shimp, 1970) and response rates (Hawkes and Shimp, 1974), the relative frequency of an IRT matches the relative reciprocal of that IRT (Shimp, 1969) if all other reinforcement parameters (magnitude, frequency, quality, etc.) are equated.

CHAPTER IV

STATEMENT OF THE PROBLEM

Studies of delay of reinforcement have shown that responding is exponentially related to the delay of reinforcement, at least in the discrete-trial task (Anderson, 1932; Perin, 1943; Hull, 1943; and Keesey, 1964). Alternatively, there are also data showing that relative frequency of responding to one of two alternatives matches the relative immediacy of reinforcement (Chung and Herrnstein, 1967; Shimp, 1969, Exp II; Herbert, 1970, Exp I and II). At least two studies reported ambiguous data as to whether relative frequency of responding matches the relative immediacy of reinforcement or decreases exponentially with delay (Herbert, 1970, Exp III; and Chung, 1965). Furthermore, Shimp (1970) and Hawkes and Shimp (1974) have found two variables (absolute rate of reinforcement and absolute rate of responding) that limit the generality of the matching function of the relative frequency of IRTs to the relative reciprocal of their duration. Therefore, more data are needed to determine the generality of matching to relative immediacy of reinforcement using the Chung and Herrnstein (1967) procedure.

Hawkes and Shimp (1974) found that when the relative reciprocal of the short IRT is held constant and the bounds of the IRT classes are varied, the relative frequency of

responding to the short IRT class deviated from matching at both short and long values for the short IRT class. An analogous manipulation in the two-key delay-of-reinforcement procedure would be to hold the relative immediacy of reinforcement constant and vary the two delays. The following data points taken from Chung and Herrnstein (1967, Fig 4) satisfy these conditions and have relative immediacies of approximately 0.80:

Delay values (sec)		Relative frequency of responding to the short delay key
0.0	6.0	0.67
2.0	8.0	0.74
4.0	16.0	0.91

Figure 13 shows these points plotted and the trend appears to be the same as that found in Hawkes and Shimp (1974). However, the interpretation of these data is not clear. First, the different points are from different subjects; second, the frequency of reinforcement was not equated for the two keys; and third, the overall rate of reinforcement was not equated for the two keys.

Experimental Hypothesis

This experiment used a two-key, concurrent VI, VI schedule with reinforcement assigned equally to the two keys and with equated overall rates of reinforcement for the two keys.

The duration of the short and long delays was increased

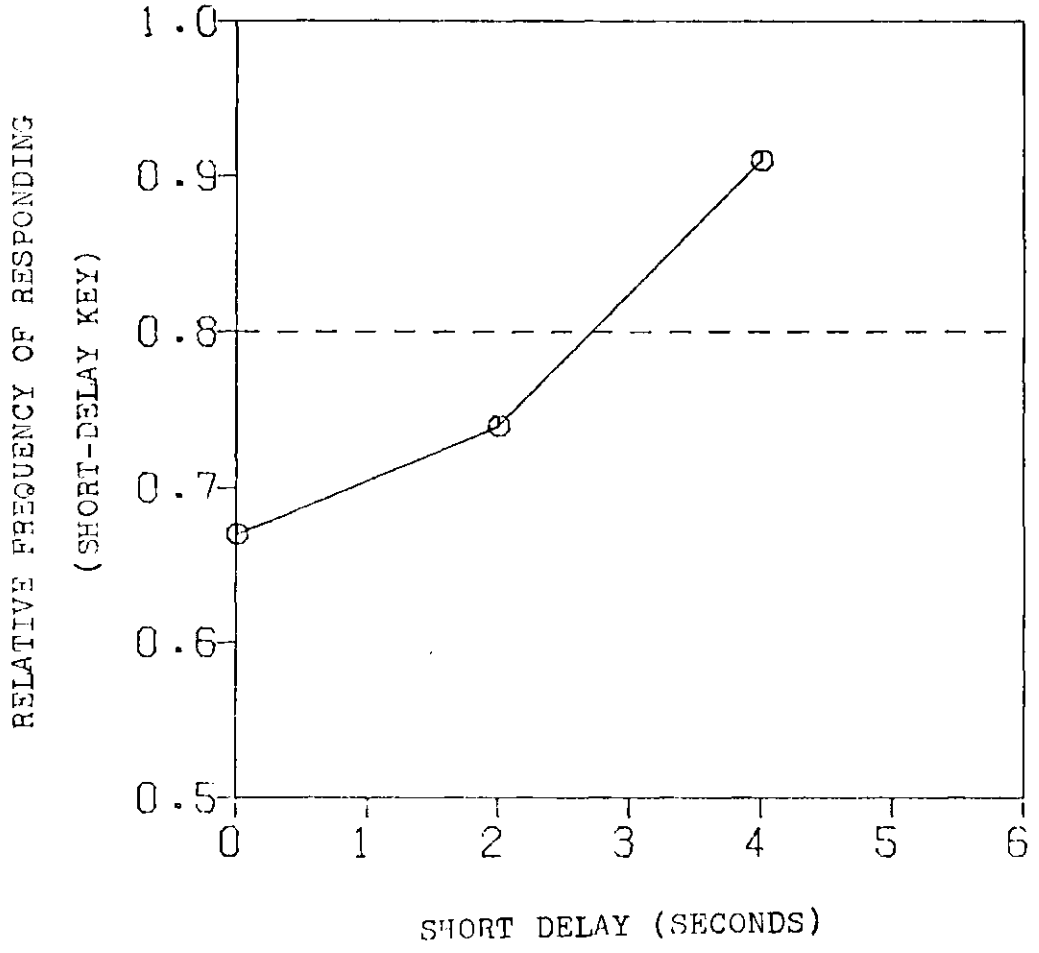


Figure 13. Relative Frequency of Responding vs. Short Delay. (These data points were replotted from Chung and Herrnstein's (1967) data for conditions that approximate a relative immediacy of reinforcement of 0.80. The dashed line indicates the matching value of 0.80.)

with the restriction that the relative immediacy of reinforcement for the short-delay key was 0.80 in all conditions other than baseline. It was hypothesized that the relative frequency of responding on the short-delay key would match 0.80. If the relative frequency of responding to the short-delay key were approximately 0.80 for all values of short and long delays (i.e., if the hypothesis is not rejected), then the view of an IRT as an operant becomes less tenable. If the relative frequency of responding to the short-delay key does not equal the matching value of 0.80 (i.e., if the hypothesis is rejected), then matching to the relative immediacy of reinforcement becomes questionable.

CHAPTER V

METHOD

Subjects

The subjects were four male White Carneaux pigeons (P3, P6, P51, and P74) maintained at approximately 80% of their free-feeding weights. Each of the subjects had previous experience in various operant conditioning experiments.

Apparatus

A chamber (36 cm x 36 cm x 36 cm) similar to that of Chung and Herrnstein's (1967) was used in the present experiment. The chamber contained two response keys, mounted 9 cm apart, that required a minimum force of 0.1 N to operate, and, when operated, provided auditory feedback. A feeder that allowed 3 sec access to mixed grain was located midway between the two keys and 20 cm below them. For the first three conditions and part of the fourth, the chamber was illuminated by a white light (110 VAC, 6 watts) except during blackouts and feeder operation. Due to repeated lamp failures, the light was not used in the remaining conditions. The response keys were transilluminated by red lights (number 1829, 28 VDC) except during blackouts and feeder operation. Masking noise was present throughout the session. The programming and recording of events was controlled by electro-mechanical devices

in an adjacent room.

Procedure

The reinforcer was made available on a variable interval (VI) 1-min schedule on each key with a 1-sec change-over delay (COD); i.e., reinforcement followed the first occurrence of a response on a key after one minute on the average, provided that at least one second had elapsed since responding changed to that key. Reinforcement frequency and overall rates of reinforcement were equated for the two keys. In all conditions, other than baseline (conditions I and III), reinforcement was delayed four times longer on one key than on the other; i.e., the relative immediacy of reinforcement on the short-delay key was 0.80 in all experimental conditions. The sequence and parameters of the conditions are given in Table 1. The short-delay key was alternated between the right and left keys to prevent sequential development of position bias. Since it was deemed necessary to gradually increase delays to maintain responding (Ferster, 1953), several conditions were replicated to assess possible sequential effects.

Stability of Responding

Condition I was given first to establish a baseline for concurrent responding and assess any effects of prior experience. Under condition I, reinforcement was delayed 1 sec on both keys. Condition III was a baseline condition, also, with 1 sec delay of reinforcement on both keys.

Conditions II, IV, V, VI, VII, and VIII were the

Table 1. Sequence and Parameters of Experimental Conditions

Condition	Session Duration (hrs)	Left-key Delay (sec)	Right-key Delay (sec)	Reinforcement Sequence (sec)
I	1	1	1	4
II	1	1	4	7
III	1	1	1	7
IV	1	8	2	12
V	1	4	16	21
VI	1	32	8	37
VII	1.5	16	64	72
VIII	2	128	32	137
V R	1	4	16	21.5
IV R	1	8	2	12.5
II R	1	1	4	9

experimental conditions in which delays differed for the two keys by a factor of four. In condition II, the delays were 1 sec and 4 sec for the left and right keys, respectively. In each succeeding condition, the delays were doubled and the short-delay key was changed to the opposite side. In the final condition (VIII), the delays were 32 and 128 sec for the right and left keys, respectively.

The pigeons were tested daily with infrequent exceptions. Each daily session was one hour long except for conditions VII and VIII, when the delays became a large portion of the session, then the sessions were increased to 1.5 and 2 hours, respectively.

Each of the conditions remained in effect until responding had stabilized and remained stable for five days, or until it appeared that responding would not stabilize. Stability was determined by 1) visual inspection of cumulative records for stable response rates on the two keys within sessions, 2) low variability in the number of responses emitted per session for the last five sessions, and 3) the relative frequency of responding on the short-delay key for each of the last five sessions being within ± 0.05 of the mean of the relative frequency of responding on the short-delay for the last five sessions.

Concurrent VI, VI Programmer

As mentioned previously, the effects of delay of reinforcement found by Chung (1965) and Chung and Herrnstein

(1967) were confounded with the relative frequency of reinforcement. This confounding resulted from the use of two independent VI programmers, one for each key. Thus, the relative frequency of reinforcement depended on the responding and generally was not 0.50. To eliminate this confounding variable and to have a VI 1-min schedule associated with each key, a single VI 30-sec tape was used. When the VI 30-sec tape made a reinforcement available, a variable ratio programmer made that reinforcement available either on the left key or on the right key in an equi-probable, quasi-random fashion. The net result of this procedure was that a VI 1-min schedule was associated with each key and reinforcement occurred equally often for both keys, regardless of responding.

Once the VI programmer made reinforcement available, it did not operate again until after the reinforcement occurred. Thus, if a reinforcement were available on the left key, for example, responding on the right key had no scheduled consequences.

The VI 30-sec tape was composed of 25 intervals ranging from 4 to 121.8 sec with an arithmetic mean of 30 sec. The 25 interval values were derived from a formula for VI intervals given by Catania and Reynolds (1968) for approximating an equal probability of reinforcement schedule with respect to time.

Reinforcement Sequence

The overall rates of reinforcement were equated for

the two keys by manipulating the duration of the reinforcement sequence for the two keys. When reinforcement became available on a key, the VI programmer stopped and the next response on that key that had satisfied the change-over delay automatically initiated the reinforcement sequence. The sequence comprised a delay period, followed by a 3-sec feeder operation, followed by a timeout. The delay period was associated with a blackout of the key lights and house light (when applicable); responding in this period had no scheduled consequences. The timeout following the reinforcement was a continuation of the blackout. At the end of the timeout, the keys and house light (when applicable) were reilluminated and the VI programmer began operating again.

In all conditions the total duration of the reinforcement sequence (delay time + 3-sec access to grain + timeout) was identical for both keys. In the experimental condition when the delay was longer on one key than on the other, the timeout on that key was shorter by an equivalent amount. Thus, the overall rates of reinforcement were equal for both keys. The duration of the reinforcement sequence for each condition is given in Table 1.

Dependent Variables

The following data were recorded during each session: 1) cumulative records of responding on the keys, 2) the number of responses on each key, 3) the number of reinforcements obtained on each key, 4) the time spent responding on each

key (i.e., the time allocated to each key), and 5) the number of changeovers from one key to the other. From these data a number of dependent variables were calculated.

The relative frequency of responding on the short-delay key was calculated by

$$\frac{P(S)}{P(S) + P(L)} \qquad (6)$$

where P is the number of responses, S is the short-delay key, and L is the long-delay key.

The relative time allocation to the short-delay key (percentage of responding time spent responding on the short-delay key) was found from

$$\frac{RT(S) - R(S)RD - CO(S)}{SD - (R(S) + R(L))RD} \qquad (7)$$

where RT is the time spent on a key (which includes the time spent in reinforcement and changeovers), R is the number of reinforcements, RD is the duration of the reinforcement sequence, CO(S) is the number of changeovers from the short-delay key, SD is the session duration, S is the short-delay key, and L is the long-delay key.

The average local rates of responding can be found by

$$\frac{P(S)}{RT(S) - R(S)RD - CO(S)} \text{ and } \frac{P(L)}{RT(L) - R(L)RD - CO(L)} \qquad (8)$$

where P is the number of responses, RT is the time spent responding on a key (including the time spent in reinforcement and changeovers), R is the number of reinforcements, RD is the reinforcement duration, CO(S) and CO(L) are the number of

changeovers from short- and long-delay keys, S is the short-delay key, and L is the long-delay key.

The relative local rate of responding on the short-delay key is then found from

$$\frac{LR(S)}{LR(S) + LR(L)} \qquad (9)$$

where LR is the local rate of responding from (8), S is the short-delay key, and L is the long-delay key.

The conventional response rates (i.e., not local) can be found for each key by

$$\frac{P(S)}{SD - (R(L) + R(S))RD} \text{ and } \frac{P(L)}{SD - (R(L) + R(S))RD} \qquad (10)$$

where P is the number of responses, SD is the session duration, R is the number of reinforcements, RD is the duration of the reinforcement sequence, S is the short-delay key and L is the long-delay key. The total response rate is the sum of these two rates:

$$\frac{P(S) + P(L)}{SD - (R(L) + R(S))RD} \qquad (11)$$

Note that the denominator of (10) and (11) is the amount of time the keys are operable (i.e., the lights-on time).

The changeover rate, the rate of changing between the two keys, is found from

$$\frac{2\ CO}{SD - (R(L) + R(S))RD} \qquad (12)$$

where CO is the number of changes from the left key to the right key and the denominator is the lights-on time.

Responses per changeover for the two keys can be found by

$$\frac{P(S)}{CO(S)} \quad \text{and} \quad \frac{P(L)}{CO(L)} \qquad (13)$$

where P is the number of responses, CO is the number of changes, S is the short-delay key, and L is the long-delay key.

The obtained overall rate of reinforcement is found by

$$\frac{R(S) + R(L)}{SD} \qquad (14)$$

where R is the number of reinforcements, SD is the session duration, S is the short-delay key, and L is the long-delay key.

All of these dependent variables are plausible response strength measures (except, of course, the obtained rate of reinforcement). The dependent variable of main interest is the relative frequency of responding to short-delay key.

CHAPTER VI

RESULTS

Among the data that were recorded included 1) the number of reinforcements obtained by responding on each key, 2) the number of responses made on each key, 3) the time allocated to responding on each key (which included time during reinforcement and the changeover), and 4) the number of changeovers from one key to the other. These data are summarized in Table 2 for each pigeon under each condition. These data are totals for the last five sessions in each condition.

P51 did not stabilize under condition VI according to the criteria that response rates be stable within and across the last five sessions. P51 was maintained on condition VI for 51 sessions, then replications were started, since its responding probably would not have stabilized at longer delays. P6 did not stabilize under condition VIII according to the criterion that the relative frequency of responding on the short-delay key be stable for the last five sessions. P6 was maintained on condition VIII for 31 sessions before it was decided that its relative frequency of responding would not stabilize.

Values of the dependent variables presented in this

chapter were calculated from the data in Table 2 and the parameters in Table 1 using equations 6 through 14 in Chapter V.

Relative Frequency of Responding on the Short-Delay Key

The relative frequency of responding on the short-delay key (from Equation 6) is shown in Figure 14 as a function of the short delay. The dashed line in Figure 14 is the matching value of 0.80 that would be predicted from the model (Equation 5) proposed by Chung and Herrnstein (1967). Clearly, these data do not fall along the matching value of 0.80. Only in the mid-range of delays that were used, did the relative frequency of responding on the short-delay key approximate the matching value of 0.80. For shorter and longer delays, the degree of preference was lower than 0.80.

Based on the data in Figure 14, the hypothesis stated in Chapter IV is rejected -- relative frequency of responding on the short-delay key did not equal the relative immediacy of reinforcement.

In Figure 14 (and in some of the succeeding figures), position bias was evident. The clearest case of position bias in Figure 14 was for P74. The up-and-down pattern in the curve corresponds to the change in the short-delay key between the left and right positions. Throughout the experiment, P74 showed a bias to the right key.

Table 2. Summary of the Data for Each Pigeon. (The entries are totals for the last five sessions for each condition. (*) indicates responding was not stable for that condition.

Pigeon	Cond.	No. of Sessions	Responses Left	Responses Right	Time Spent (sec) Left	Time Spent (sec) Right	Change-overs	No. of Rein.
3	I	22	10566	10535	9335	12841	2091	383
	II	22	13449	7085	10442	11506	2276	435
	III	32	14068	9180	11020	11082	2239	455
	IV	32	8545	8904	9540	11673	1857	394
	V	18	7394	6630	10136	10132	1261	330
	VI	36	2754	8907	6636	12626	597	232
	VII	24	12682	2572	16294	11974	572	233
	VIII	32	2722	3792	16357	20360	343	191
	V R	19	11154	7935	10829	9974	1309	331
	IV R	9	8235	12755	7856	13011	1345	389
6	I	30	7583	7422			3797	438
	II	21	11842	7343			5133	450
	III	32	13014	7834			4778	453
	IV	32	6407	9227			3129	385
	V	18	15980	2434	13718	5637	705	302
	VI	35	1993	9322	6479	12628	625	235
	VII	24	9606	3183	16190	11848	521	250
	VIII*	31	2919	1904	17378	16835	269	174
	V R	17	15790	1344	14392	4320	369	272
	IV R	26	8060	12354	8827	12658	1667	391

Table 2. (Continued)

Pigeon	Cond.	No. of Sessions	Responses Left	Responses Right	Time Spent (sec) Left	Time Spent (sec) Right	Change-overs	No. of Rein.
51	I	30	14469	12695	11730	9708	1630	469
	II	22	24661	16315	12815	8555	1787	461
	III	32	26897	19753	11314	11008	2362	442
	IV	32	10076	18423	5799	13955	1071	375
	V	18	10633	2140	14229	5218	661	246
	VI*	51	756	4462	3425	14762	163	132
	IV R	19	21382	8935	13774	7396	1261	377
	II R	24	16019	21130	8016	12802	1319	419
74	I	22	5229	9175	9434	11355	1414	437
	II	21	9046	8790	9924	10649	1447	433
	III	32	4222	7348	8828	11604	1297	407
	IV	32	4639	8687	7361	12374	1066	375
	V	18	5786	3196	10959	8597	718	311
	VI	35	1830	6471	6794	12073	407	237
	VII	24	2767	2601	13824	13906	348	229
	VIII	32	2206	2753	16992	19513	264	186
	V R	17	3419	2815	9222	10256	692	303
	IV R	11	2571	6797	7032	12401	673	361

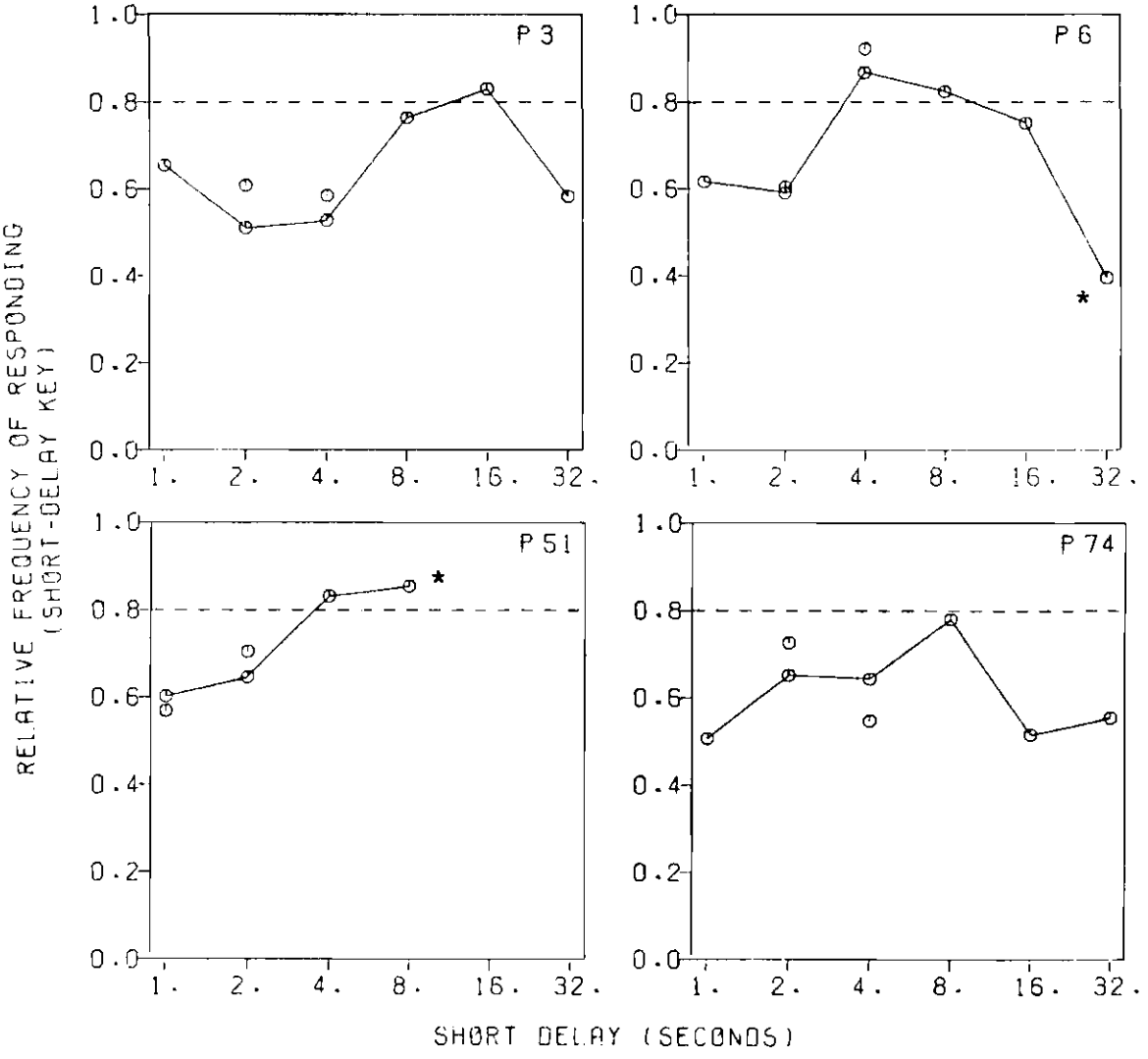


Figure 14. Relative Frequency of Responding on the Short-Delay Key as a Function of the Short Delay. (The dashed line indicates the prediction from Chung and Herrnstein (1967). The unconnected data points represent the replication values. (*) indicates unstable responding for that condition.)

Time Allocation and Local Rates of Responding

By using the time allocated to each key ("Time Spent" in Table 2), two other measures of preference were obtained: relative time allocation to the short-delay key and relative local rate of responding on the short-delay key.

The relative time allocation on the short-delay key is the percentage of the time during which the key lights were illuminated that responding was occurring on the short-delay key (Equation 7). The relative time allocation to the short-delay key is shown in Figure 15 as a function of the short delay. These curves are very similar to the curves for the relative frequency of responding in Figure 14. The data for P6 are not available for conditions II and IV because its high changeover rate made it impossible to record the time allocation accurately.

The local rate of responding on a key is the rate of responding while responding on that key; i.e., the time spent responding on the other key is neglected in the calculations, as can be seen in Equation 8 for calculating the local rates. These local rates of responding are plotted in Figure 16 for both keys as a function of the short delay. The two local rates of responding were very similar with no systematic difference between the two keys. There was a slight decline in the local rates as the delays increased (except for P51, which had a sharp decline).

The relative local rate of responding on the short-

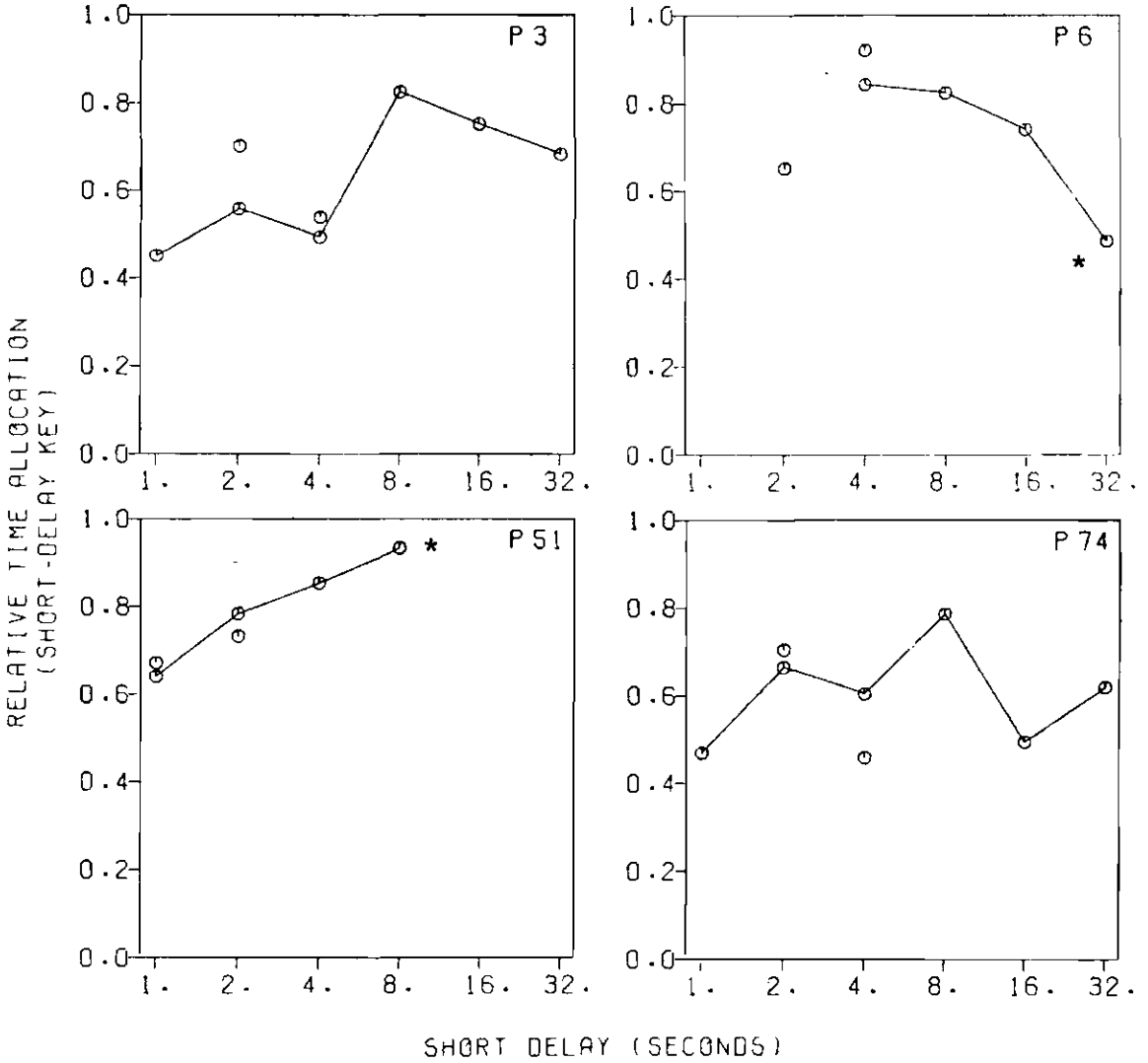


Figure 15. Relative Time Allocation to the Short-Delay Key as a Function of the Short Delay. (The unconnected data points represent the replication values. (*) indicates unstable responding for that condition.)

delay key was found from the local rates of responding and Equation 9. The relative local response rate on the short-delay key is plotted in Figure 17 as a function of the short delay. As would be expected from Figure 16, the relative local response rate was approximately 0.50 and showed no trends (however, P51 was consistently below 0.50 as would be expected from Figure 16). (Note that the data are not plotted in Figures 16 and 17 for P6 under conditions II and IV for previously mentioned reasons.)

Conventional Response Rates

The conventional method for calculating response rates for concurrent operants is to divide the number of responses by the session duration (Catania, 1966). Since a considerable portion of each session was consumed by delays and time-outs, this procedure was modified to use key-lights-on time rather than session duration (Equation 10). The total response rate then is the sum of the response rates for the two keys (Equation 11). The response rates for each key and the total response rate are plotted in Figure 18 as a function of the short delay. The response rate for the short-delay key was higher than the response rate for the long-delay key in all conditions when responding was stable (which reflects the fact that the relative frequency of responding on the short-delay key was greater than 0.50).

The total response rate was relatively stable with increasing delays,with the following exceptions: P51's rate

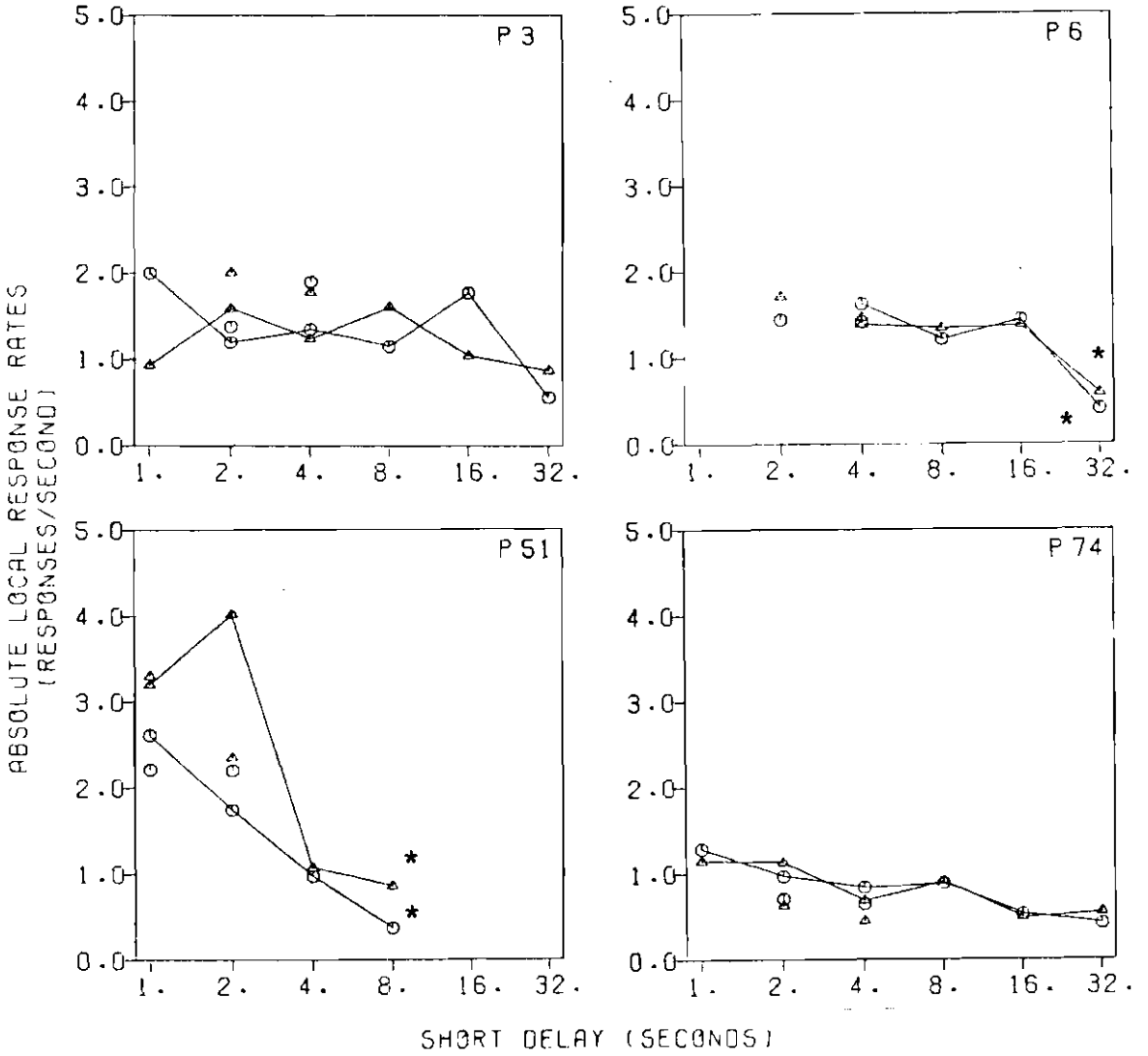


Figure 16. Absolute Local Response Rates on Both Keys as a Function of the Short Delay. (The octagon and the triangle represent the short- and long-delay keys, respectively. The unconnected data points represent replication values. (*) indicates unstable responding for that condition.)

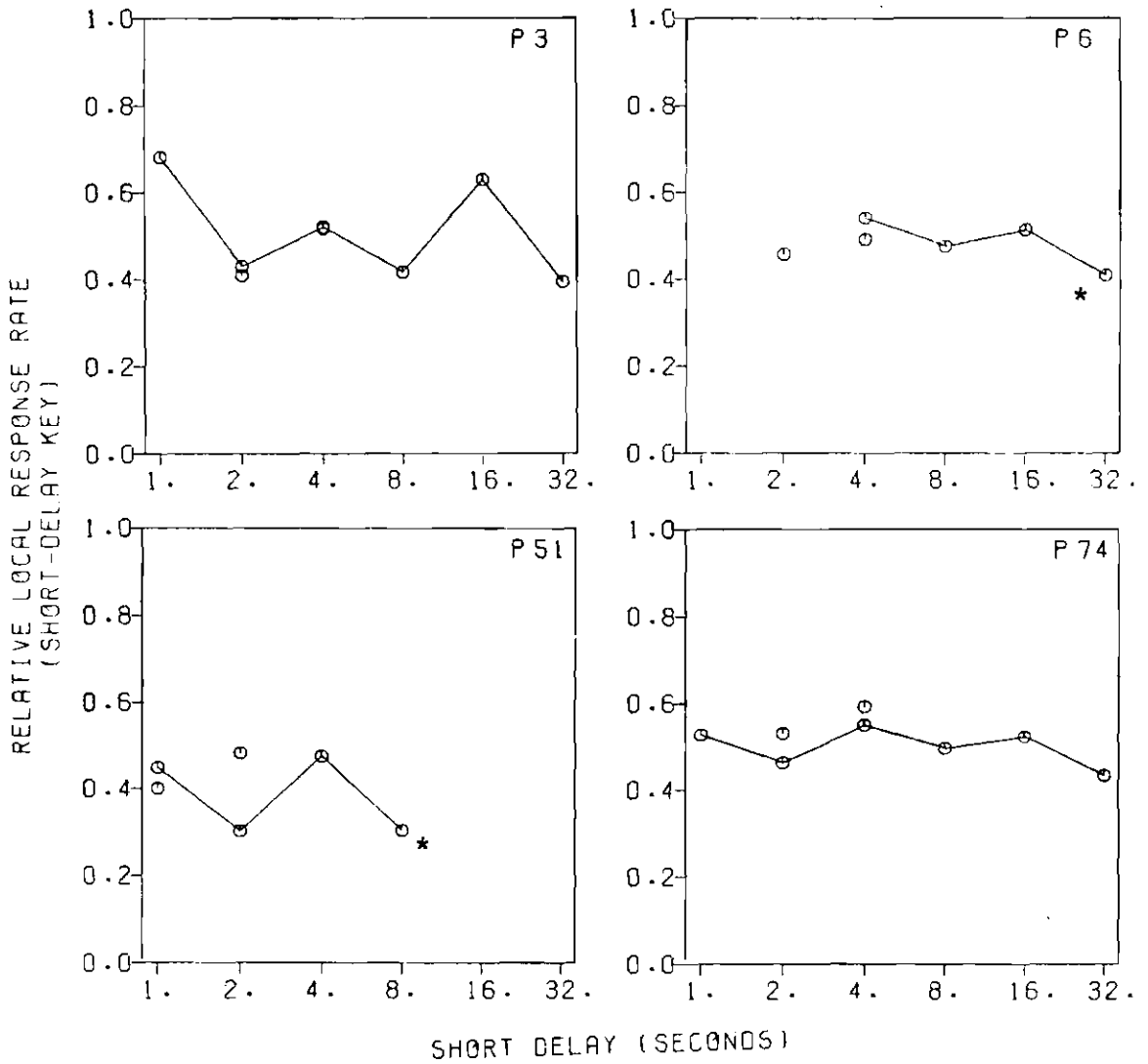


Figure 17. Relative Local Response Rate as a Function of the Short Delay. (The unconnected data points represent replication values. (*) indicates unstable responding for that condition.)

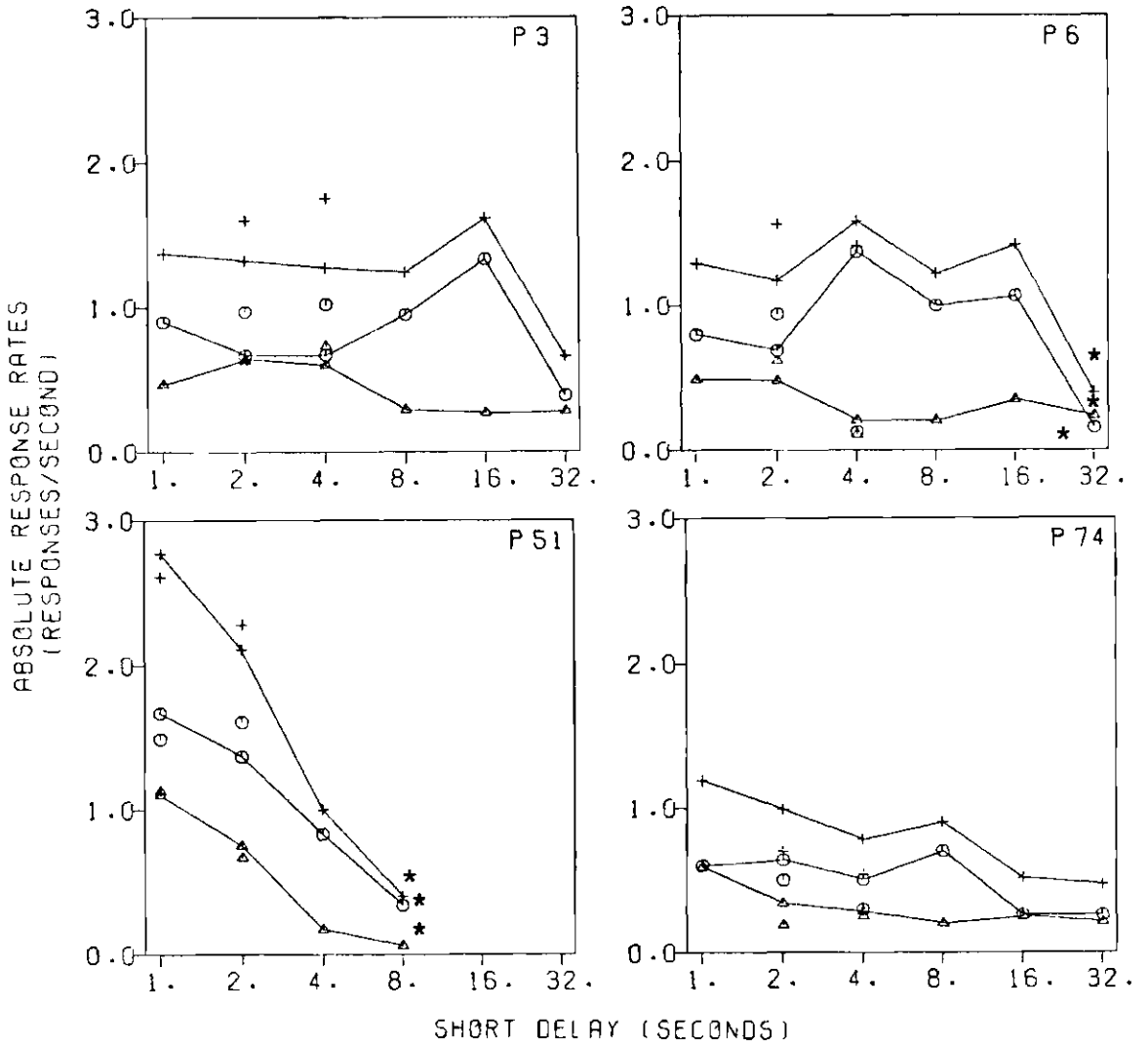


Figure 18. The Absolute Response Rate on Both Keys and the Total Response Rate as a Function of the Short Delay. (The octagon and triangle represent the short- and long-delay keys, respectively; the plus represents the total response rate. The unconnected data points represent replication values. (*) indicates unstable responding for that condition.)

decreased sharply as the delays were increased and under condition VIII, P3's and P6's rate decreased considerably. This general stability in total response rate was anticipated from previous experimental data (Chung and Herrnstein, 1967; Chung, 1965; Ferster, 1953; and Nevin, 1974). The effect of condition VIII on total response rate will be discussed further in a later section.

Changeover Rate and Responses per Changeover

The changeover rate (frequency of changes between keys per unit time), as calculated by Equation 12, is plotted as a function of short delay in Figure 19. There was a steady decrease in changeover rate for all pigeons as the delays were increased. P6 started out with a very high changeover rate, but by condition V the changeover rate was comparable to that of the other pigeons. It was the high changeover rate that made it impossible to record time allocation accurately for P6, as previously mentioned.

The number of responses per changeover (Equation 13) for the two keys is shown in Figure 20 as a function of the short delay. At all stable values, the number of responses per changeover was higher on the short-delay key than on the long-delay key. This higher value reflects the fact that the relative frequency of responding on the short-delay key was greater than 0.50. A greater difference between the two curves in Figure 20 indicates a greater preference for the higher curve. There was also a trend in that the responses

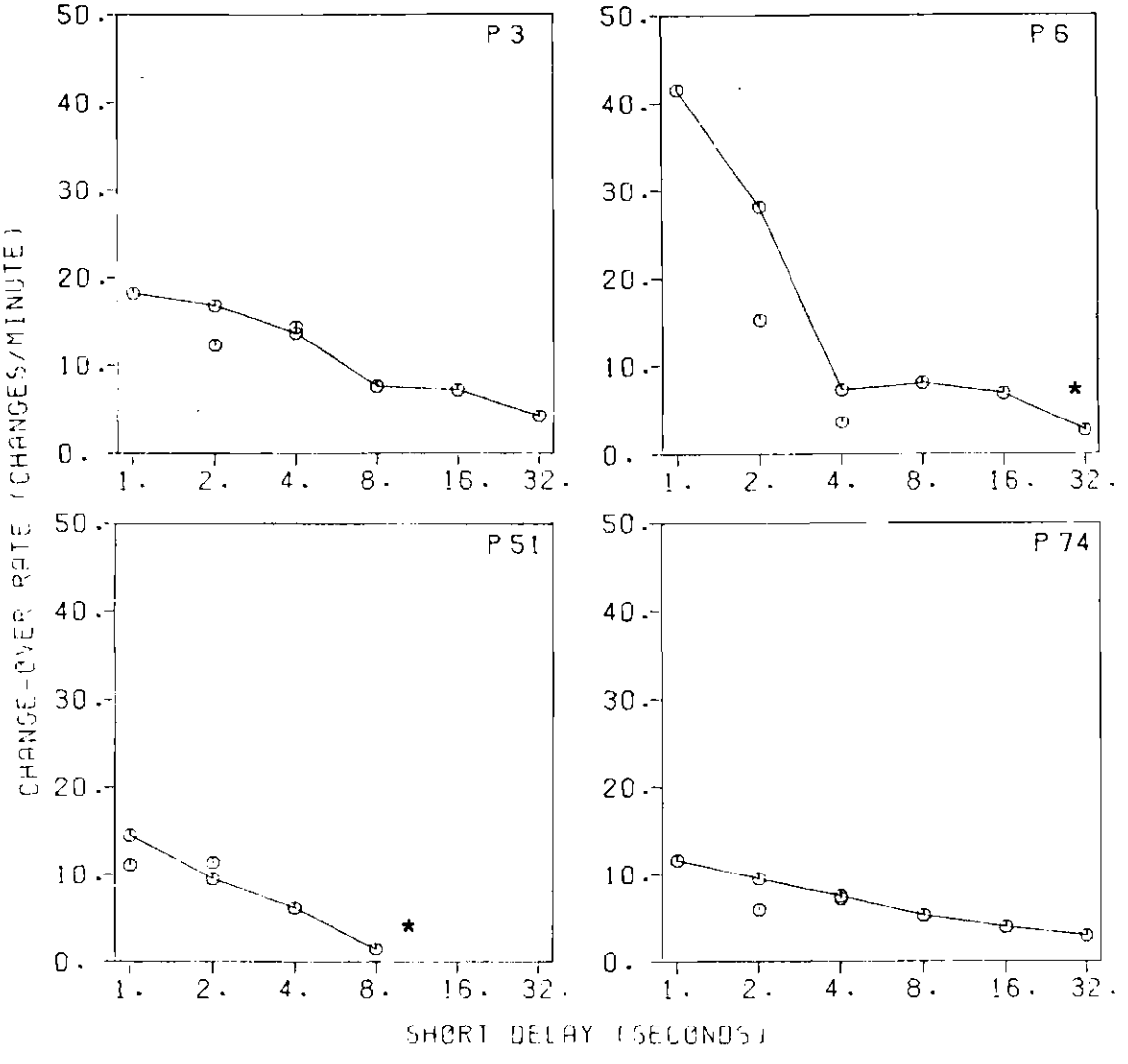


Figure 19. Changeover Rate as a Function of the Short Delay. (The unconnected data points represent replication values. (*) indicates unstable responding in that condition.)

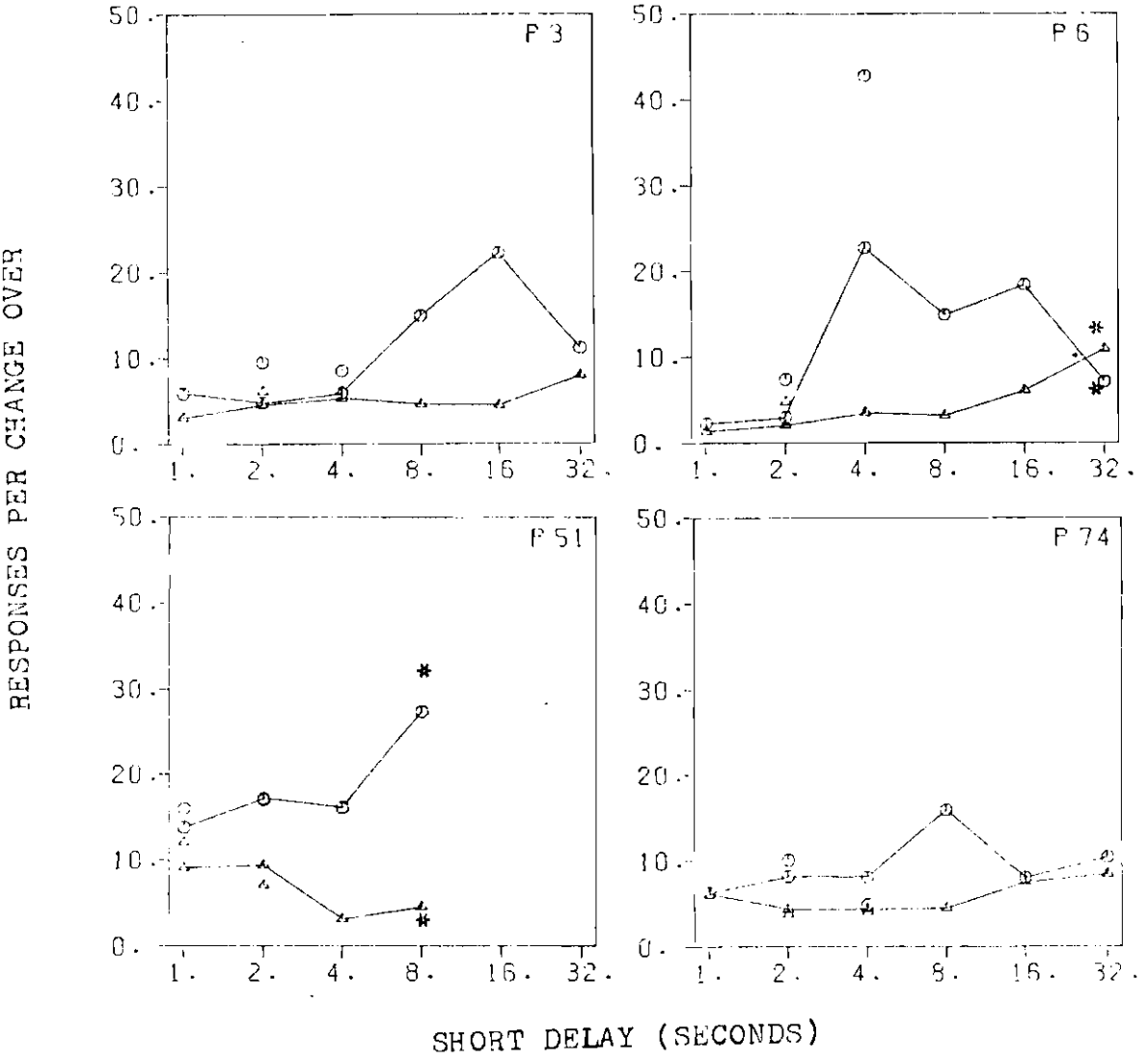


Figure 20. Responses Per Changeover on Both Keys as a Function of the Short Delay. (The circle and triangle represent the short- and long-delay keys, respectively. The unconnected data points represent the replication values. (*) indicates unstable responding for that condition.)

per changeover averaged for the two keys increased with increasing delays.

The decrease in the changeover rate with increasing delays (Figure 19) can be attributed to two factors. First, as preference increased with increasing delays, fewer changeovers were made. Second, as the delays increased more responses per changeover were made. The first factor partially explains the second; however, as the preference declined at the longer delays, there is no obvious reason for more responses per changeover on both keys.

Cumulative Records

The response patterns that were engendered by the experimental conditions can be typified as a response run (i.e., sequence of responses) on one key followed by a response run on the other key. Cumulative records that are representative of the last five sessions for conditions II, IV, V, VI, and VII for P6 are shown in Figure 21.

Some of the dependent variables that have been discussed can be seen graphically in Figure 21. For example, the slope of the cumulative records is roughly equal to the conventional response rate. The response rate was always higher on the short-delay key. The number of responses emitted was always higher on the short-delay key. It follows, therefore, that the relative frequency of responding on the short-delay key was higher than 0.50. The change in the relative frequency of responding on the short-delay key can be seen as

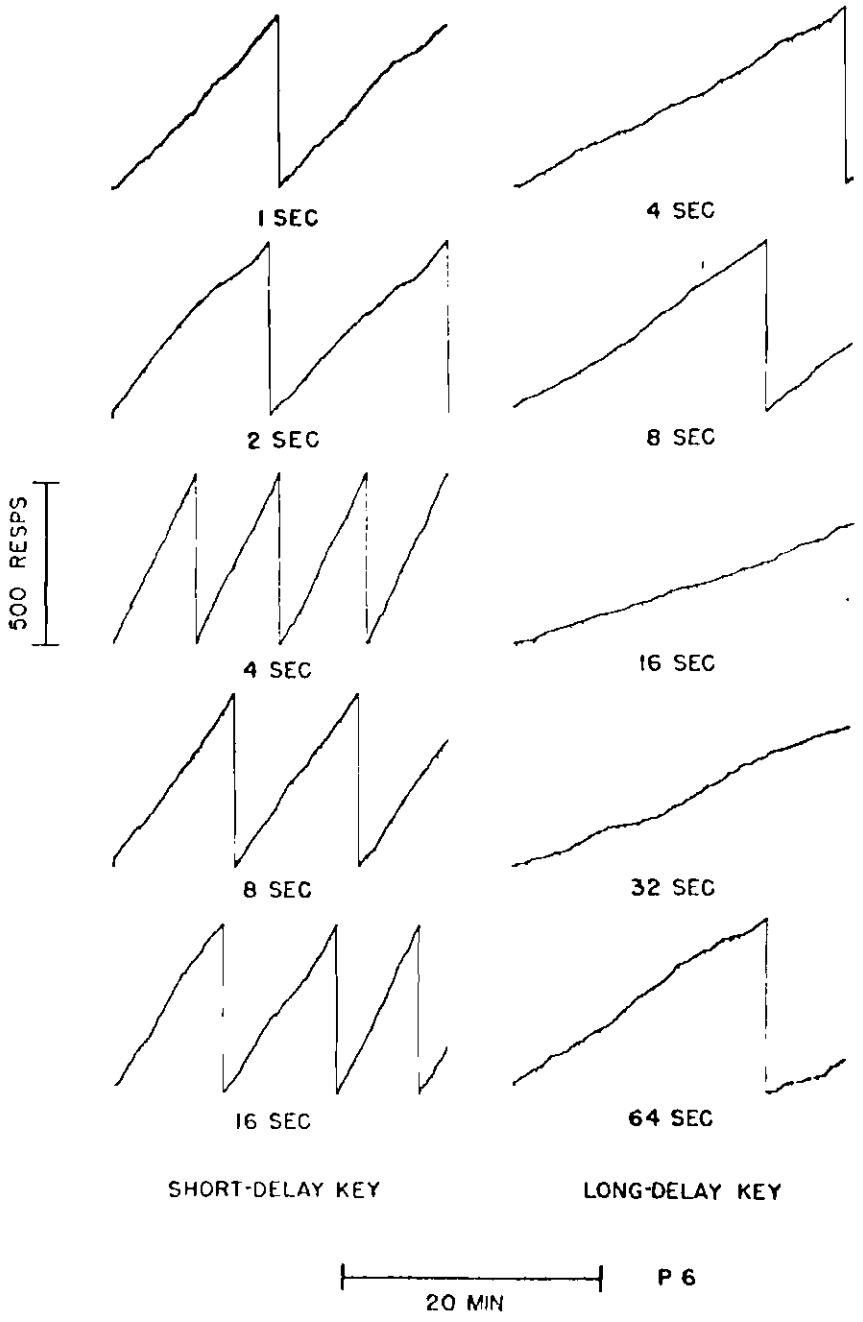


Figure 21. Cumulative Records of Responding for P6 under Conditions II, IV, V, VI, and VII. (These records are typical of the last five sessions for each condition.)

delays were increased. The rate of responding on the short-delay key increased, then decreased; while the rate of responding decreased, then increased on the long-delay key. Thus, the relative frequency of responding on the short-delay key increased, then decreased, with increasing delays.

Obtained Reinforcement Rate

As the delays increased, an increasing portion of each session was consumed by longer reinforcement sequences. Thus, the overall rate of reinforcement (number of reinforcements per hour) -- both maximum and obtained -- decreased as the delays were increased. The maximum and the obtained reinforcement rates (Equation 14) are plotted in Figure 22 as a function of the short delay.

In general, the pigeons' responding was "efficient" in that the obtained reinforcement rate was a high percentage of the maximum reinforcement rate, even at the longer delays. The obvious exception is P51: as the delays increased, the percentage of the maximum that it obtained decreased.

It should be recalled from Chapter III that Shimp (1970) found that the relative frequency of the shorter IRT did not match the relative reciprocal of the shorter IRT at reinforcement rates lower than 30 per hour (Figure 11). The dashed line in Figure 22 represents this value of 30 reinforcements per hour. When the obtained reinforcement rate is below this line, the response pattern may be governed by the reinforcement rate rather than the delays. The low rate of

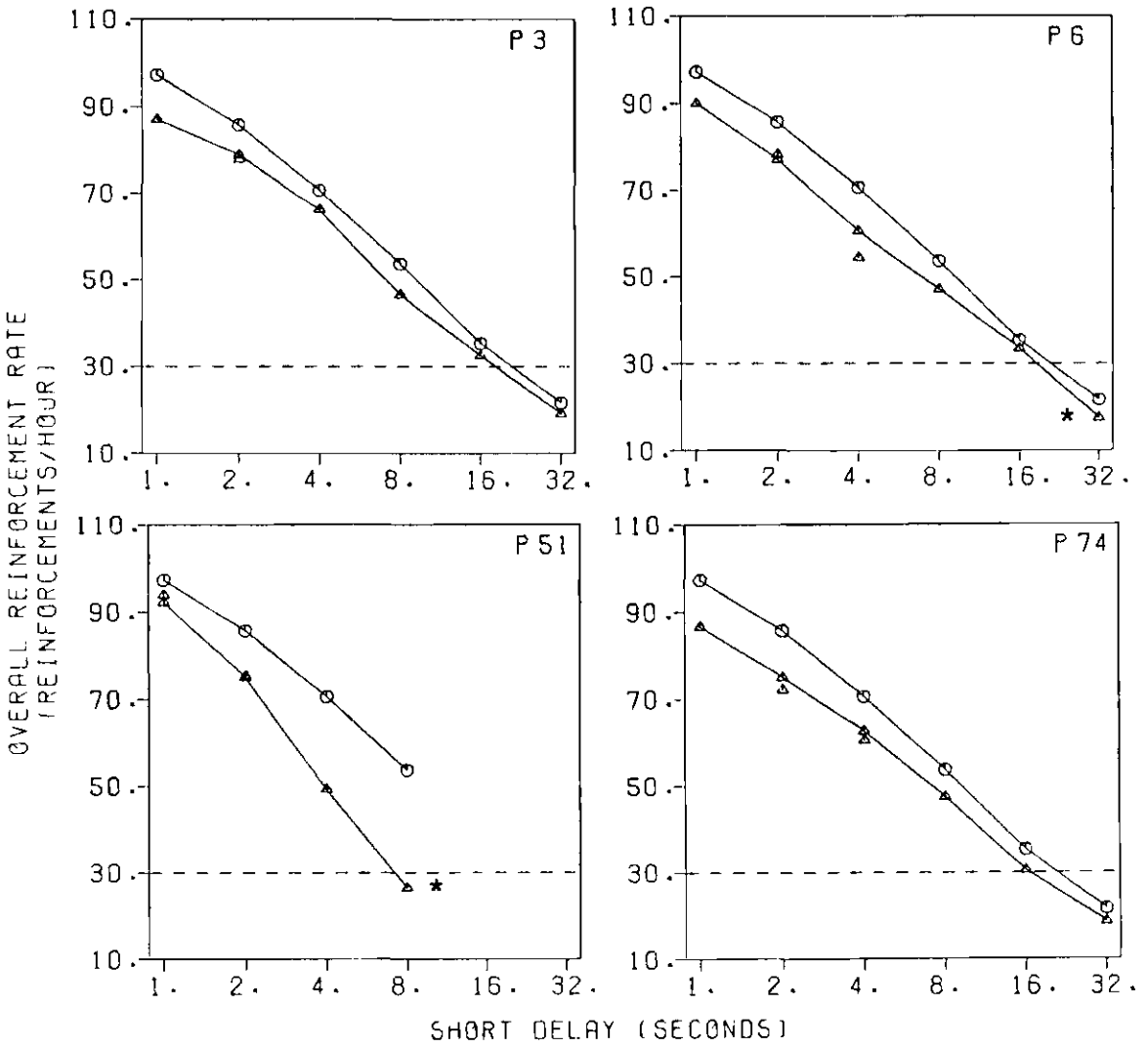


Figure 22. The Maximum and Obtained Overall Reinforcement Rate as a Function of the Short Delay. (The circle and triangle represent the maximum and obtained reinforcement rates, respectively. The unconnected data points represent replication values. (*) indicates unstable responding for that condition. The dashed line indicates the reinforcement rate below which Shimp (1970) found no matching.)

reinforcement in condition VI for P51 was a possible cause for, and certainly the result of, the unstable low response rate. Likewise, the decline in response rate for P6 and P3 (Figure 18) under condition VIII might have been the result of the low reinforcement rate. However, unlike P51, their low response rate did not cause the low reinforcement rate, since their "efficiency" was still very high.

CHAPTER VII

DISCUSSION

Matching to Relative Immediacy

Choice and Delays

Chung and Herrnstein (1967) proposed a model for choice under two-key concurrent schedules of reinforcement in which the reinforcers are delayed. This model is a matching relation (Equation 5) which states that the relative frequency of responding on the short-delay key matches (equals) the relative immediacy of reinforcement for that key (immediacy is the reciprocal of delay).

Subsequently, Shimp (1968, 1969) found that when a pigeon is given a choice between two IRTs on a single response key, the relative frequency of responding in the shorter IRT matched the relative reciprocal of the duration of the short IRT. This matching relation suggested to Shimp (1969) that the durations of IRTs function in a manner analogous to delays of reinforcement, and thus an IRT is an operant with properties similar to those of a response on a key.

Shimp (1970) and Hawkes and Shimp (1974) described two variables that limit the generality of the relative frequency of the short IRT matching the relative reciprocal of the duration of the short IRT: 1) the obtained rate of reinforcement (Shimp, 1970) (see Figure 11), and 2) the absolute durations

of the IRTs (Hawkes and Shimp, 1974) (see Figure 12).

The present experiment incorporated a procedure similar to that used by Hawkes and Shimp (1974); i.e., the relative immediacy of reinforcement was held constant and the delays were varied. The purpose was to determine if the model proposed by Chung and Herrnstein (1967) (Equation 5) is also of limited generality.

The results, shown in Figure 14, clearly indicate that the relative frequency of responding on the short-delay key does not match the relative immediacy of reinforcement for all the values of delay in the present experiment. Thus, the absolute values of delay are also important determinants of choice, perhaps in addition to the ratio of delays. That is, if one were to hazard an extrapolation to other values of relative immediacy, the degree of preference would be lower than the matching value if the absolute delays were very short or very long, regardless of the relative immediacy. However, the maximum point of preference in the mid-range of delays may be a function of the relative immediacy of reinforcement. The present experiment was not designed to determine if the effects of delays on choice are due to absolute delays alone or absolute delays together with relative delays. The experiment did determine, however, that choice was not uniquely a function of the relative delay.

Implications for IRT Theories

Since Shimp (1969) found that the same matching relation

held for IRTs and delays (i.e., a reciprocal relation), he concluded that the two might have similar properties. An exception was found for the IRT matching relation (Hawkes and Shimp, 1974) in that matching was a special case of the absolute durations of the IRTs (Figure 12). At the time, this lack of matching represented a breakdown in the analogy; however, the present data indicate that the matching relation for delays is also a special case of the absolute delays.

Analyzing the analogy any more than above is not presently possible. The present data cannot be directly compared to Hawkes and Shimp's (1974) data because there is no known function to relate delay value to IRT value in absolute measures. How short must a short delay be to be equivalent to a short IRT? How long must a long IRT be to be equivalent to a long delay? The answers to these questions are yet unknown. It is possible that the relative frequency of the short IRT might have decreased had longer IRTs been used. Thus, the question of whether IRTs are analogous to delays is still an open question with more data needed.

Time Allocation

Baum and Rachlin (1969) cited reasons for using relative time allocation as a measure of choice rather than relative frequency of responding (e.g., Herrnstein, 1961; Chung, 1965; Chung and Herrnstein, 1967). Consider their logic as follows:

$$P = (LR)\ T \qquad (15)$$

where P is the frequency of responding, LR is the local response rate, and T is the time spent responding. Thus,

$$\frac{P(L)}{P(L) + P(R)} = \frac{LR(L)T(L)}{LR(L)T(L) + LR(R)T(R)} \quad (16)$$

where L and R are the two alternatives. Herrnstein (1961) assumed T(L) = T(R), since both keys were equally available; thus,

$$\frac{P(L)}{P(L) + P(R)} = \frac{LR(L)}{LR(L) + LR(R)} \quad (17)$$

However, there is considerable evidence (including Figures 16 and 17) that the local rate of responding is relatively insensitive to schedule and reinforcement parameters (Catania, 1961 and 1962; Blough, 1963). What does change is the time allocation to a response. Therefore, assuming LR(L) - LR(R),

$$\frac{P(L)}{P(L) + P(R)} = \frac{T(L)}{T(L) + T(R)} \quad (18)$$

Considering the data shown in Figure 14, 15 and 17, the present experiment apparently supports the notion of Baum and Rachlin (1969). The discrepancies between relative frequency of responding and relative time allocation, as well as the difference between the two local response rates, can be explained by a shortcoming in the data gathering equipment. Only two measures of time allocation were taken, one for each operant. A third measure of time allocation is required to assert that these data support Baum and Rachlin's (1969) notion, and that is time spent not responding. The time

allocation to responding on a key (Table 2) included pause times that followed response runs on that key.

Even with this discrepancy in data, two tentative conclusions can be reached: 1) delays affect relative time allocation, and 2) delays do not affect relative local response rates. An important question that remains unanswered is how time spent not responding is affected over a wide range of delays. For example, P51's relative local response rate was below 0.50 (Figure 17) for all delays. If the tentative conclusions above were true, one must conclude that pauses following responding on the preferred key were longer than the pauses following responding on the other key for P51.

The Matching Law

The empirically formulated matching law (Herrnstein, 1961; Chung and Herrnstein, 1967; Neuringer, 1967; Reynolds, 1963; Catania, 1963; and Herrnstein, 1970) holds that the relative strength of an operant (relative frequency of responding or relative time allocation) matches 1) relative frequency of reinforcement, 2) relative magnitude of reinforcement, or 3) relative immediacy of reinforcement. Rachlin (1971) proposed that these relative parameters of reinforcement act multiplicatively; i.e.,

$$\frac{P_L}{P_R} = \frac{T_L}{T_R} = \frac{R_L}{R_R} \cdot \frac{A_L}{A_R} \cdot \frac{I_L}{I_R} \cdot \frac{X_L}{X_R} \qquad (19)$$

where P is responses, T is time allocation, R is the number

of reinforcements, A is magnitude of reinforcement, I is immediacy of reinforcement, X is any other parameter of reinforcement, and L and R are the two alternatives.

Rachlin (1971) stated that the matching law is not itself an empirical law, but a statement of assumptions on how reinforcement acts on responding. That is, the matching law holds that choice matches the relative value of reinforcement:

$$\frac{T_L}{T_R} = \frac{V_L}{V_R} \qquad (20)$$

where V is the value of reinforcement. Therefore, value of a reinforcer is defined by choice, so the matching law cannot be disproved. (To disprove Equation 20, V must be defined independently of behavior and then demonstrate that the relative time allocation does not equal relative value of reinforcement, and, at present, there is no means of assessing V independently of behavior.)

If one were to find

$$\frac{T_L}{T_R} = f(X_L, X_R) \quad \text{and} \quad f(X_L, X_R) \neq \frac{X_L}{X_R} \qquad (21)$$

where all other reinforcement parameters are constant, it must be concluded from Equation 20 that

$$\frac{V_L}{V_R} = f(X_L, X_R) \qquad (22)$$

Such is the case with the present data,

$$\frac{P_L}{P_R} = f(I_L, I_R) \quad \text{and} \quad f(I_L, I_R) \neq \frac{I_L}{I_R} \qquad (23)$$

Therefore,

$$\frac{V_L}{V_R} \neq \frac{I_L}{I_R} \qquad (24)$$

and empirical formulations (such as Equation 19) are in general not valid.

Overall Rate of Reinforcement

Since the obtained overall rate of reinforcement declined as delays and reinforcement sequences were lengthened, any effect of the overall obtained reinforcement rate is confounded with the effect of delays. However, that the total response rate (Figure 18) was in general relatively unaffected by the increasing delays (and, therefore, decreasing reinforcement rate) is an indication that the reinforcement rate did not generally affect choice. In the conditions where there was a sharp decline in total response rate (P6 and P3 under condition VIII and P51 under all conditions), it is not possible to rule out the effects of overall reinforcement rate on choice.

Data from other experiments (e.g., Chung, 1965; Chung and Herrnstein, 1967; and Shimp, 1970) indicate that this interpretation is correct. Chung (1965) found that the decrease in reinforcement rate had no effect on total response rate. Shimp (1970) found that the degree of preference

decreased below approximately 30 reinforcements per hour.

Thus, the low degree of preference for the short-delay key under condition VIII may be due (partially or totally) to the low obtained reinforcement rate. There is no readily apparent explanation for the total response rate for P51, other than extreme sensitivity to overall reinforcement rate.

Delay of Reinforcement

Traditionally, delay of reinforcement has been regarded as a parameter of reinforcement. Delay of reinforcement can also be considered as a schedule of reinforcement.

Delay Schedules

Reinforcement can be delayed according to one of two procedures. In the first, reinforcement would occur some time, d, after the to-be-reinforced response, regardless of the behavior that occurs during d. In the second, reinforcement would occur some time, d, after the to-be-reinforced response and any response of that same class that occurs during d restarts the delay at d. The first procedure is a fixed time (FT) schedule of reinforcement; i.e., reinforcement under a FT d schedule occurs d seconds after some event, regardless of behavior in that period. The second procedure is a differential reinforcement of other behavior (DRO) schedule of reinforcement; i.e., under a DRO d schedule of reinforcement, reinforcement occurs d seconds after some event if, and only if, a response in a certain class has not occurred in that

period. If a response in a certain class does occur, the DRO d schedule is reinitialized for d seconds.

Sequences of Schedules

If a DRO d or FT d schedule is used for a delay of reinforcement of d seconds, the event that initiates the schedule is the to-be-reinforced response. The response that initiates the DRO d or FT d schedule may itself be under another schedule. Two schedules, where the satisfaction of the first initiates the second, form a sequence of schedules (Morse, 1966).

If there is an external stimulus change associated with the change of schedules, this sequence of schedules is termed a chained schedule of reinforcement. Under a chained schedule, the first schedule is called the initial link and the second schedule is called the terminal link. If there is no stimulus change associated with the change in schedules, this sequence is called a tandem schedule of reinforcement.

Thus, if one wanted to schedule a "delay" of reinforcement of d seconds for responding on a VI t schedule, four distinct procedures are available:

Chained VI t, FT d	Tandem VI t, FT d
Chained VI t, DRO d	Tandem VI t, DRO d

Concurrent Chains

If only the initial links of two independent chained schedules are concurrently available for responding, then the two chained schedules are called concurrent chained schedules

(Autor, 1969). Under concurrent chained schedules, the initial links are both available. When appropriate responding occurs during either of the initial links, there is a stimulus change and only the terminal link associated with that initial link becomes available for responding. Reinforcement follows the completion of the terminal link. The terminal link may remain in effect for a fixed duration or a fixed number of reinforcements prior to presenting the two initial links again.

Concurrent chained schedules have been used to measure choice or preference: the relative frequency of responding in one of the initial links is a measure of preference for the terminal link associated with that initial link (Autor, 1969; Herrnstein, 1964; Fantino, 1969; Squires and Fantino, 1971; Davison and Temple, 1973). An example of concurrent chained schedules is shown in Figure 23 in which the initial links are VI and the terminal links are FI. When appropriate responding occurs during the initial link VI on one key, the stimulus (key color) changes to that associated with the terminal link and the other key becomes inoperative. When appropriate responding occurs during the terminal link, the reinforcer is presented, followed by the two concurrently available initial links. The relative frequency of responding on the left key during the initial links is a measure of preference for the terminal link on the left key, compared to the terminal link on the right key.

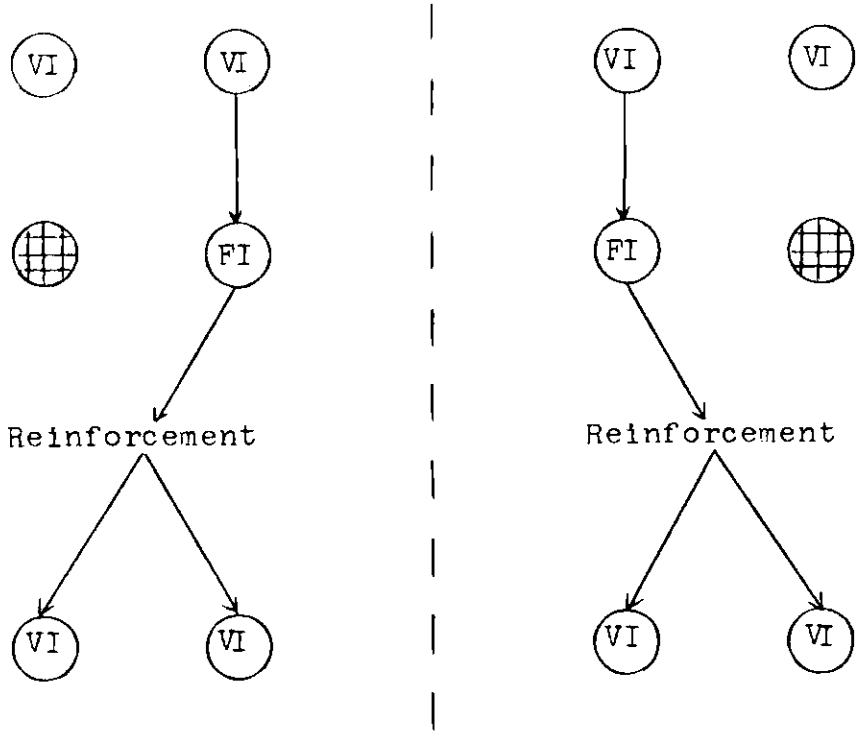


Figure 23. Two Possible Sequences of Events for Concurrent Chained Schedules of Reinforcement. (In this example, the initial links are VI and the terminal links are FI. When the initial link on one key has been satisfied, the key color changes to that associated with the FI schedule and the other key becomes inoperative. When the FI schedule has been satisfied, the reinforcer is presented followed by the concurrently available initial links.)

Reformulation of the Experimental Procedure

In Chapter V, the experimental procedure was given in terms of concurrent VI 1-min, VI 1-min with delays of reinforcement. Since the delay was scheduled such that reinforcement followed the to-be-reinforced response by a fixed time regardless of behavior during that time, the delay schedule was a fixed time (FT) schedule. Also, since the two VI 1-min schedules were concurrently available and there was a stimulus change associated with the onset of either FT schedule (the keys went dark), the schedule of reinforcement may be described as a concurrent chained (VI 1-min, FT d(s)) (VI 1-min, FT d(l)), where d(s) and d(l) are the delays of reinforcement (short and long, respectively).

It follows, then, that the preference for d(s) over d(l) is the relative frequency of responding during the initial links on the VI 1-min associated with d(s). These data are the same as presented in Figure 14.

The advantage of considering the present experimental procedure as concurrent chained schedules is that predictive models for choice, other than Chung and Herrnstein's (1967), are available for comparison with the present findings.

Models for Choice under Concurrent Chained Schedules

Several models are available for predicting choice under concurrent chained schedules (Fantino, 1969; Squires and Fantino, 1971; Davison and Temple, 1973). None of the available models were specifically designed or empirically

tested when both terminal links were FT schedules. However, since these models were designed for use with FI terminal links, they might also apply to FT terminal links. The only difference between a FI and a FT schedule is that the FI requires a single response and the FT requires no responses. Furthermore, Neuringer (1969) found that when the terminal links were FI and FT of equal durations, they were equally preferred.

Herrnstein (1964) concluded from experimental data that the relative frequency of responding in the initial links matched the relative rate of reinforcement in the terminal links (which were VI and VR). If these data were extrapolated to the case where both terminal links were FT, then the relative rate of reinforcement in the terminal links would be identical to the relative immediacy of reinforcement. Therefore, Herrnstein's (1964) experiment predicted the results of Chung and Herrnstein (1967) by assuming that delay was an FT schedule and that the model applied to FT terminal links. The prediction for the present data has been discussed already.

Fantino (1969) stated that Herrnstein's (1964) formulation did not account for many concurrent chained schedules because it did not include the initial link durations. Fantino's (1969) model applied to the present procedure is

$$\frac{P_S}{P_S + P_L} = \begin{cases} \dfrac{T - d_S}{(T-d_S) + (T-d_L)} & \text{if } d_S < T,\ d_L < T \\ 1 & \text{if } d_S < T,\ d_L > T \end{cases} \qquad (25)$$

where P is the number of responses, T is the expected time to reinforcement from the onset of the initial links, d is the expected time to reinforcement from the onset of the terminal link (i.e., delay), S is short, and L is long. In the present experiment, T is (30 + d(S)/2 + d(L)/2) seconds.

Squires and Fantino (1971) changed Equation 25 to allow for multiple reinforcements per entry into a terminal link. Their model applied to the present procedure is

$$\frac{P_S}{P_S + P_L} = \begin{cases} \dfrac{r_S(T-d_S)}{r_S(T-d_S) + r_L(T-d_L)} & \text{if } d_S < T,\ d_L < T \\ 1 & \text{if } d_S < T,\ d_L > T \end{cases} \qquad (26)$$

$$\text{and} \qquad r_S = \frac{n_S}{t_S + n_S d_S} \qquad r_L = \frac{n_L}{t_L + n_L d_L}$$

where P is the number of responses, T is the expected time to reinforcement from the onset of the initial links, d is the duration of the terminal links, n is the number of reinforcements per entry into a terminal link, t is the duration of the initial links, S is short, and L is long. In the present experiment, d(S) and d(L) were the delay values; T was (30 + d(S)/2 + d(L)/2) seconds; t(S) and t(L) were both 60 seconds; and n(S) and n(L) were both 1.0.

Another concurrent chained schedule model was proposed by Davison and Temple (1973). This model in terms of the present experiment is

$$\frac{P_S}{P_L} = \frac{R_S}{R_L} \cdot E \cdot \frac{d_L}{d_S} \qquad (27)$$

where P is responses, R is the reinforcement rate, E is the ratio of obtained entries to a terminal link to the entries provided by the schedule parameters, d is the terminal link duration plus the duration of the reinforcement, S is short, and L is long. In this experiment, E = 1.0, since reinforcements were equated on the two keys. Therefore,

$$\frac{P_S}{P_L} = \frac{(60 + d_L)}{(60 + d_S)} \cdot \frac{(d_L + 3)}{(d_S + 3)} \qquad (28)$$

Applying these models (Equations 5, 25, 26, and 27) to the parameters in Table 1, the curves presented in Figure 24 result. The present data are also plotted in Figure 24 as an average for the four pigeons (for clarity of presentation). Clearly, the present data are more in accordance with the concurrent chained schedules of Fantino (1969), Squires and Fantino (1971), and Davison and Temple (1973) than with the matching value (Herrnstein, 1964; Chung and Herrnstein, 1967).

At the longer delays when preference decreased, the present data deviate the most from all of the predictive models. Since these models were based on relatively short terminal links, more experimental data are required for longer duration terminal links. Whether the decrease in preference was due to reinforcement rate or terminal link duration, these models should predict this decrease since both of these

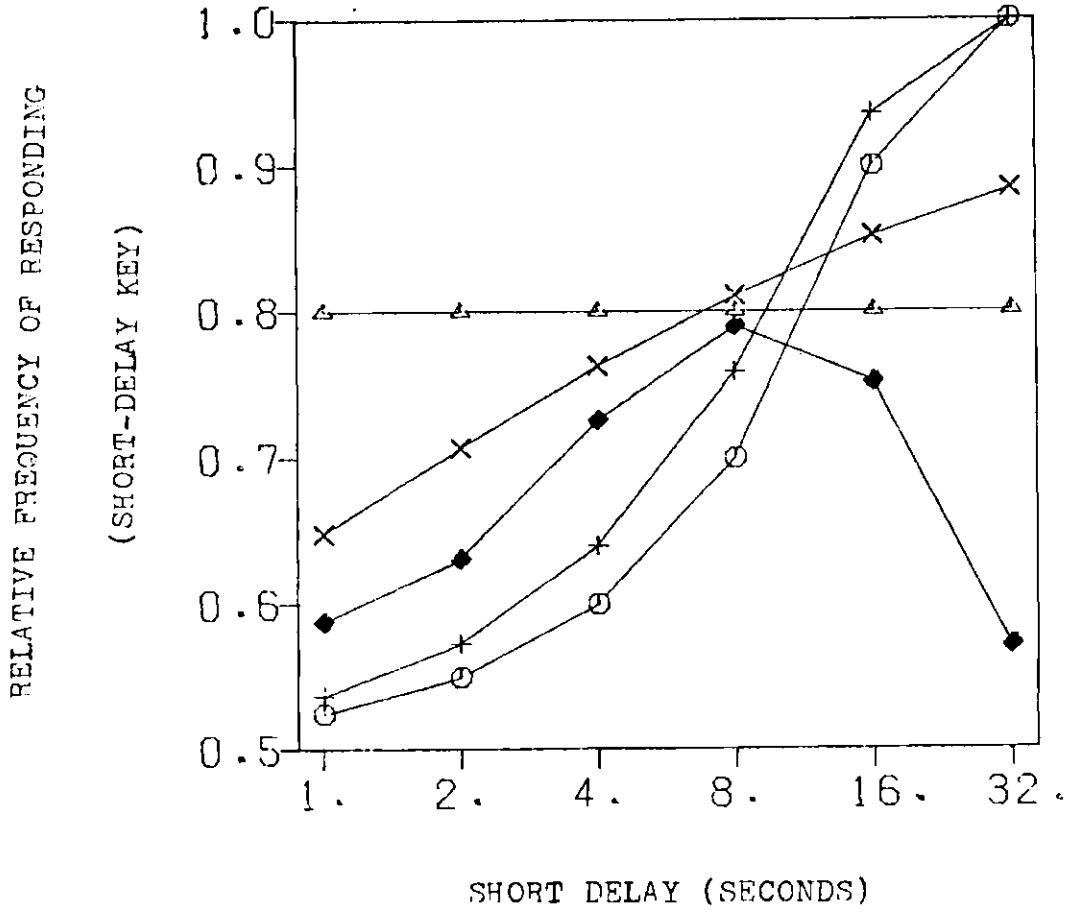


Figure 24. Comparison of Predictive Models for Concurrent Chained Schedules with the Data from the Present Experiment. (The symbols for the predictive models are as follows: triangle, Chung and Herrnstein, 1967; circle, Fantino, 1969; plus, Squires and Fantino, 1971; and cross, Davison and Temple, 1973. The filled squares are the data obtained in this experiment averaged for the subjects under each condition.)

variables appear in the models (Equations 25, 26, and 27). Picking one model as the best predictor is beyond the scope of the present data since only one parameter (terminal link durations) was manipulated.

The conclusions that can be drawn from Figure 24 are that delays of reinforcement can be considered as a schedule arrangement and, in particular, the present experiment provides evidence that delays of reinforcement under concurrent schedules of reinforcement are very similar to concurrent chained schedules with fixed interval terminal links. Future experimentation on the effects of delay of reinforcement should include precise specification of the delay arrangements for comparison with other known schedule effects.

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